National Aeronautics and Space Administration

# NAS-Wide Fast-Time Simulation Study for Evaluating Performance of UAS Detect-and-Avoid Alerting and Guidance Systems


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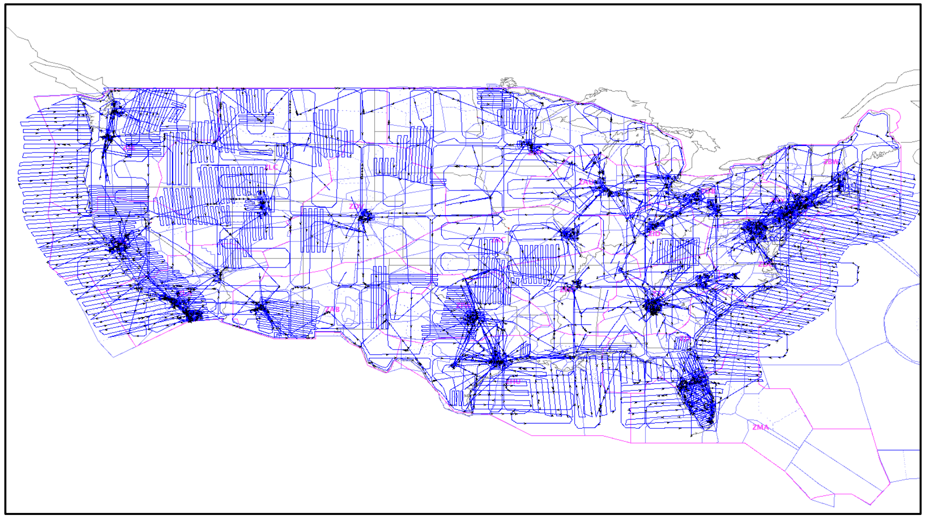
# Objectives

- Explore the tradespace of DAA alerting parameters to investigate alerting performance metrics of RTCA SC-228 Minimum Operational Performance Standards (MOPS).
  – Evaluate the sensitivity of alerting parameters on the performance metrics of each DAA alert type: preventive, corrective, and warning alerts
  – Evaluate the effect of sensor uncertainty on DAA alerting and guidance performance

- Help refine and validate MOPS alerting and guidance requirements.

# Simulation Platform

- Airspace Concept Evaluation System (ACES) and JADEM Fast-time Simulation Framework
  - Simulate NAS-wide air traffic operations of UAS and VFR traffic



- Various realistic encounters between UAS and VFR traffic in civil airspace
  - Historical cooperative and non-cooperative VFR Traffic
    - The 84th Rader Evaluation Squadron (RADES) Data (on April 4, 2012)
  - Proposed UAS Flights
    - 18 different types of UAS missions generated by Intelligent Automation Inc.
- UAS DAA Alerting and Guidance System [JADEM]
  - Higher fidelity surveillance model: Honeywell sensor models
  - Dead-reckoning based DAA alerting logic
  - OmniBands-based guidance logic

# UAS Missions Overview

* Developed under contract with IAI Inc.

| Mission Types | UAS Group | Flight Duration | Cruise Altitude | Cruise Speed (KTAS) | Flight Pattern |
|---|---|---|---|---|---|
| Aerial Imaging and Mapping | Aerosonde Mk 4.7 | 40~90 min | 300 ft ~3000 ft. AGL | 44 to 51 | Radiator-grid pattern |
| Air Quality Monitoring | Shadow-B/Sierra | 1-4 hrs. | 4k,5k, and 6k ft AGL | 74 to 89 | Radiator-grid pattern |
| Air Taxi Cirrus | Cirrus SR22T | 20~45 mins | 6k-11k | 153 to 166 | Point-to-Point |
| Air Taxi Mustang | Cessna Mustang | 20~45 mins | 10k-32k | 156 to 340 | Point-to-Point |
| Airborne Pathogen Tracking | Shadow-B (RQ7B)/NASA Sierra | 1-4 hrs. | 3,000 ft. to 10,000 ft. AGL | 72 to 97 | Radiator-grid pattern |
| Border Patrol | Predator-B (MQ-9) | 2-7 hrs. | 5,000 ft. to 15,000 ft. AGL | 129 to 173 | Radiator-grid pattern |
| Cargo Delivery | Cessna 208 | 20~200 mins. | 626 ft. to 25,000 ft. MSL | 137 to 172 | Point-to-Point |
| Flood Inund. Mapping | Aerosonde Mk 4.7 | 1-4 hrs. | 4,000 ft. AGL | 46 to 51 | Grid pattern |
| Flood Stream Flow | Aerosonde Mk 4.7 | | 4,000 ft. AGL | 46 to 51 | Grid pattern and/or along stream direction |
| Law Enforcement | Aerosonde Mk 4.7 /FALCON | 3~8 hrs | 3,000 ft. AGL | 44 to 51 | Three types of pattern: 1) grid pattern, 2) random, 3) outward spiral |
| Maritime Patrol | Global Hawk (RQ4A) | 4.5~14 hrs. | 5,000 ft. to 35,000 ft. AGL | 151 to 321 | Radiator-grid pattern |
| Point Source Emission | Shadow-B | 0.5~5 hrs. | 3,000 ft. AGL | 72 to 80 | Round-the-clock |
| Spill Monitoring | Shadow-B | 40~260 mins | 3,000 ft. to 13,000 ft. AGL | 72 to 93 | Radiator-grid pattern |
| Strategic Wildfire Monitoring | Ikhana | ~ 20 hrs. | 31,000 MSL | 209 | Grid pattern |
| Tactical Fire Monitoring | ScanEagle/Shadow-B | 1~1.5 hrs. | 3,000 ft. AGL | 72 to 75 | Circular flight path following the perimeter of a wildfire |
| Traffic Monitoring | Shadow-B | ~ 2 hrs. | 1,500 ft. AGL | 58 to 84 | Geo-spatial monitoring flight path |
| Weather Data Collection | Global Hawk | 1.5~13 hrs. | 5,000 ft. to 35,000 ft. AGL | 151 to 321 | Radiator-grid pattern |
| Wildlife Monitoring | Aerosonde Mk 4.7 | ~40 min | 3,000 ft. AGL | 44 to 51 | Radiator-grid pattern |

# VFR Intruder Traffic

- VFR Traffic Scenario
  - One day in April 2012
- Types of intruders with different equipage
  - Intruders operating under IFR (Not considered in this study)
- It is assumed that ownship unmanned aircraft are equipped with onboard radar, active transponder (Mode-S), and ADS-B surveillance system to detect the intruder aircraft with different equipage.

| VFR | Transponder Equipage | Percentage |
|---|---|---|
| Coop-VFR 1 | ADS-B Out and Mode-S | 82% (OSED: 71%*) |
| Coop-VFR 2 | Mode-S Only | 18% (OSED: 14%*) |
| Non-Coop VFR | No Transponder (or Mode A transponder) | 15~20% (OSED: 15%*) |

*Based on OSED document: Table A-1. Intruder Equipage Assumptions Post-2020

# Honeywell Sensor Models*

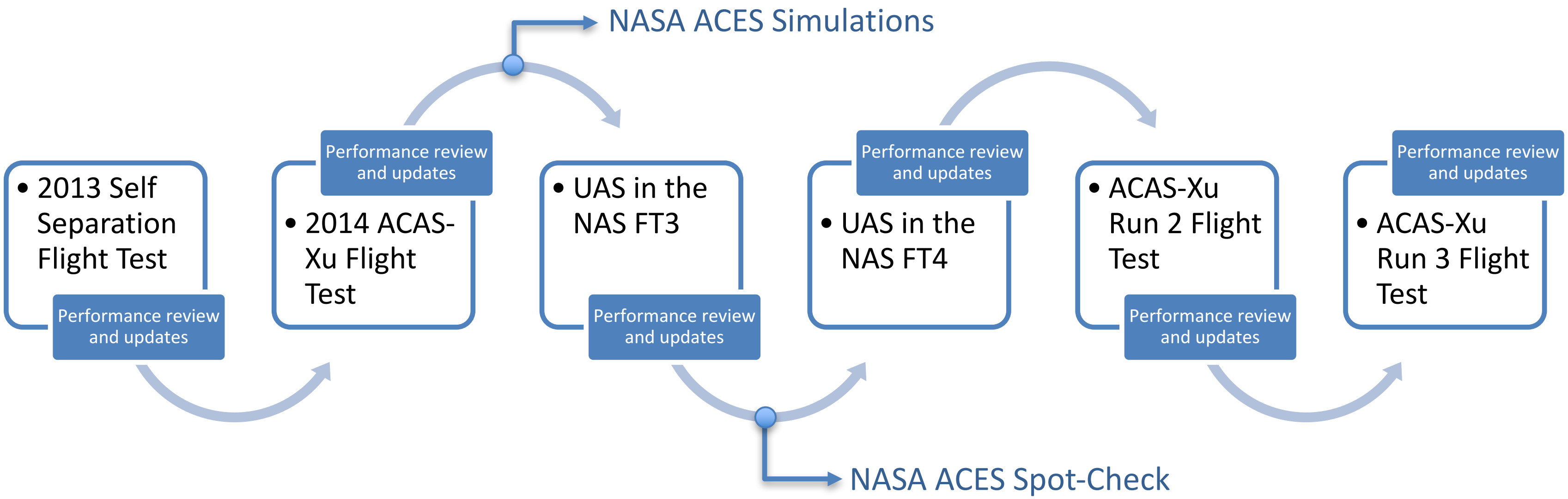
* Honeywell Sensor Model Version: Version 10

| | ADS-B | TCAS Mode-S | TCAS Mode-C | Radar |
|---|---|---|---|---|
| Detection Range (nmi) | Max = 90 nmi<br>Min = 0 nmi | Max = 30 nmi<br>Min = 0 nmi | Max = 14 nmi<br>Min = 0 nmi<br>(performance changes by quadrant) | Max = 13.3 nmi (FT3)<br>Min = 1000 ft |
| Azimuth Angle (deg) | +/- 180 deg | +/- 180 deg | +/- 180 deg | +/- 135 deg |
| Elevation (deg) | +/-20 deg | +20 deg<br>-10 deg | +20 deg<br>-10 deg | +/-20 deg |
| Relative Altitude (ft) | N/A | +/- 3000ft<br>(Target of Interest) | +/- 3000ft<br>(Target of Interest) | N/A |

- The parameter values for sensor models were set based on Flight Test 3 (FT3) data.

# Honeywell Tracker

## Tracker Development/Versions



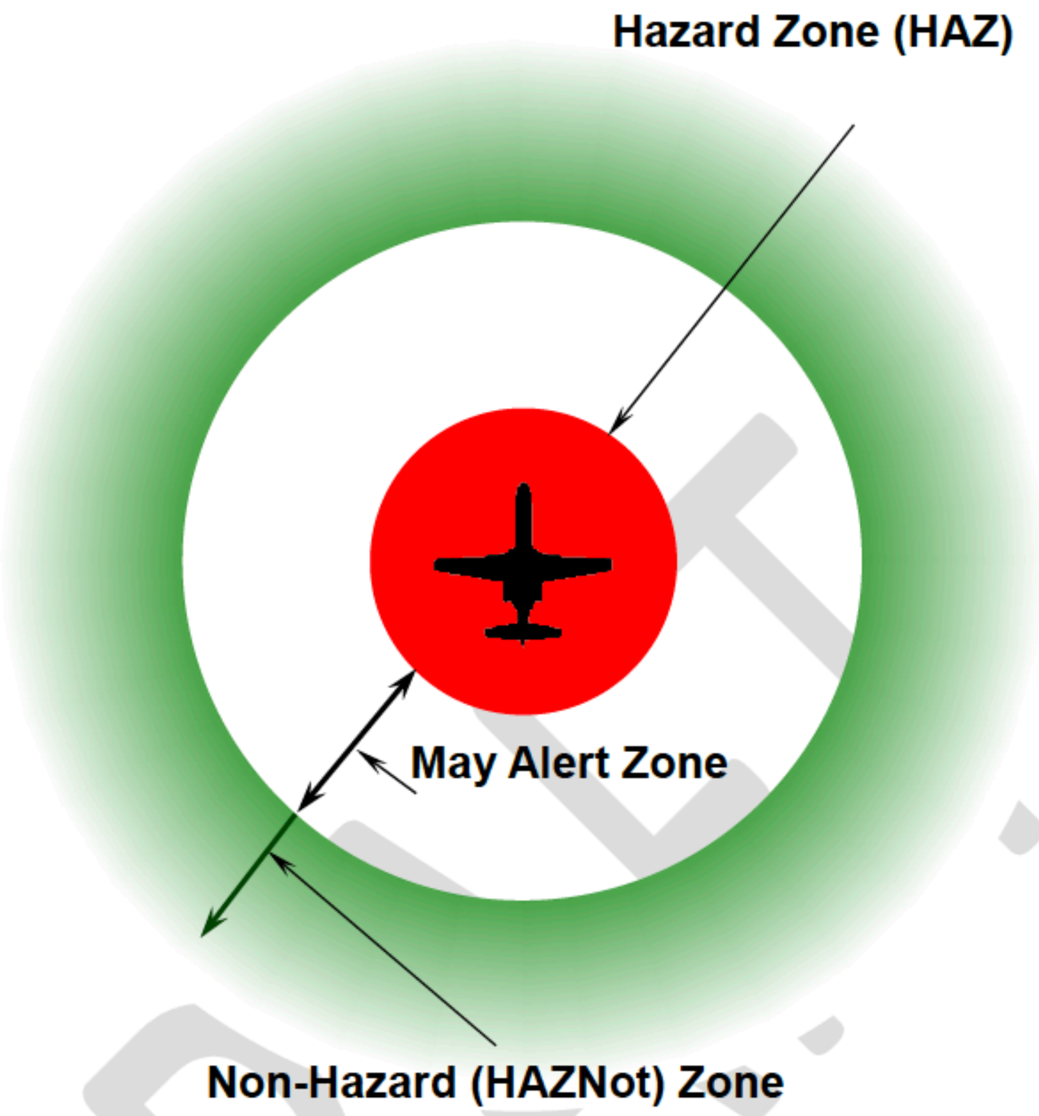

- Honeywell has been developing DAA trackers for several years
  - Development and flight testing since 2013
- Results presented here are based on a version used in FT3
  - Results spot checked with FT4 version

# Experimental Plans for DAA Alerting Performance Study

# Alerting Thresholds (SC-228 MOPS)

| Alert Type → | | Preventive Alert | Corrective Alert | Warning Alert |
|---|---|---|---|---|
| Alert Level → | | Caution | Caution | Warning |
| Hazard Zone | $\tau^*_{mod}$ (Seconds) | 35 | 35 | 35 |
| | DMOD and HMD* (NM) | 0.66 | 0.66 | 0.66 |
| | $h^*$ (Feet) | 700 | 450 | 450 |
| | Minimum Average Time of Alert (Seconds) | 55 | 55 | 25 |
| Hazard Zone Alert Times | Late Threshold ($THR_{Late}$) (Seconds) | 20 | 20 | 15 |
| | Early Threshold ($THR_{Early}$) (Seconds) | 75 | 75 | 55 |
| Non-Hazard Zone | $\tau^*_{mod}$ (Seconds) | 110 | 110 | 90 |
| | DMOD and HMD* (NM) | 1.5 | 1.5 | 1.2 |
| | VMOD (Feet) | 800 | 450 | 450 |

# Zones Used in Alert Evaluation



# Unmitigated Simulation Experiment

- Independent Factors
  - Parameters for alerting logic
    1) Alert time before HAZ (sec): Predicted time to Loss of Well Clear (LoWC)
    2) HMD/DMOD threshold (nm)
    3) Vertical separation threshold (ft)
  - Existence of sensor noise
    - Noise-free tracks vs. tracks from Honeywell sensor model
- Dependent Variables
  - MOPS' alerting performance metrics (only for unmitigated simulation results)
    - Required/early correct alert, short alert, late alert, missed alert, correct/early permissible alert, permissible non-alert, incorrect alert, and correct non-alert
    - Analysis of alert times: Average time of alert

# SC-228 Alerting Performance Metrics

- Performance metrics analyzing tracks with HAZ Violation (Alert Required)
  - Probability of Missed Alert: P(MA)
  - Probability of Late Alert: P(LA)
  - Probability of Short Alert: P(SA)
  - Probability of Early Required Alert: P(ERA)
  - Probability of Correct Required Alert: P(CRA)
  - Average Time of Alert Before HAZ violation (AAT)
  - Alerting Ratio (AR)

- Performance metrics analyzing tracks with MAZ violation (Alerts Permissible)
  - Probability of Permissible Non-Alert: P(PNA)
  - Probability of Early Permissible Alert: P(EPA)
  - Probability of Permissible Alert: P(PermA)
  - Average Number of Alerts Issued per Encounter (ANA)

- Performance Metrics analyzing tracks in Non-Hazard Zone (Alerts Undesirable)
  - Probability of Correct Non-Alert: P(CAN)
  - Probability of Incorrect Alert: P(IA)

# Experiment Design

| Independent Factor | Levels for Each Factor | | |
|---|---|---|---|
| Alerting Time Threshold (sec): Predicted Time to Loss of Well-Clear (LoWC) | Alert Type | | |
| | Warning Alert | Corrective Alert | Preventive Alert |
| | 20 | 35 | 35 |
| | 35 | 50 | 50 |
| | 50 | 65 | 65 |
| HMD/DMOD (nm) | Same For All Alert Types<br>0.66, 0.90, 1.15, 1.5 nm | | |
| Vertical Separation Threshold (ft) | 450 | 450 | 700 |
| | 600 | 600 | 850 |
| | 750 | 750 | 1000 |
| Sensor Uncertainty | 0: No Sensor Uncertainty<br>1: Sensor Uncertainty | | |

* Total 72 runs of unmitigated simulations = 3 X 4 X 3 X 2

# Final Experiment Matrix

| Experiment Condition | Alerting Time Threshold (sec) | | | HMD/DMOD Threshold (nmi) | Vertical Separation Threshold (ft) | | | Honeywell Sensor Noise |
|---|---|---|---|---|---|---|---|---|
| | Warning Alert | Corrective Alert | Preventive Alert | Same for all alert levels | Warning Alert | Corrective Alert | Preventive Alert | |
| Exp_001 | 20 | 35 | 35 | 0.66 | 450 | 450 | 700 | Yes |
| Exp_002 | 35 | 50 | 50 | 0.66 | 450 | 450 | 700 | Yes |
| Exp_003 | 50 | 65 | 65 | 0.66 | 450 | 450 | 700 | Yes |
| Exp_004 | 20 | 35 | 35 | 0.90 | 450 | 450 | 700 | Yes |
| Exp_005 | 35 | 50 | 50 | 0.90 | 450 | 450 | 700 | Yes |
| Exp_006 | 50 | 65 | 65 | 0.90 | 450 | 450 | 700 | Yes |
| Exp_007 | 20 | 35 | 35 | 1.15 | 450 | 450 | 700 | Yes |
| Exp_008 | 35 | 50 | 50 | 1.15 | 450 | 450 | 700 | Yes |
| Exp_009 | 50 | 65 | 65 | 1.15 | 450 | 450 | 700 | Yes |
| Exp_010 | 20 | 35 | 35 | 1.50 | 450 | 450 | 700 | Yes |
| Exp_011 | 35 | 50 | 50 | 1.50 | 450 | 450 | 700 | Yes |
| Exp_012 | 50 | 65 | 65 | 1.50 | 450 | 450 | 700 | Yes |
| Exp_013 | 20 | 35 | 35 | 0.66 | 600 | 600 | 850 | Yes |
| Exp_014 | 35 | 50 | 50 | 0.66 | 600 | 600 | 850 | Yes |
| Exp_015 | 50 | 65 | 65 | 0.66 | 600 | 600 | 850 | Yes |
| Exp_016 | 20 | 35 | 35 | 0.90 | 600 | 600 | 850 | Yes |
| Exp_017 | 35 | 50 | 50 | 0.90 | 600 | 600 | 850 | Yes |
| Exp_018 | 50 | 65 | 65 | 0.90 | 600 | 600 | 850 | Yes |
| Exp_019 | 20 | 35 | 35 | 1.15 | 600 | 600 | 850 | Yes |
| Exp_020 | 35 | 50 | 50 | 1.15 | 600 | 600 | 850 | Yes |
| Exp_021 | 50 | 65 | 65 | 1.15 | 600 | 600 | 850 | Yes |
| Exp_022 | 20 | 35 | 35 | 1.50 | 600 | 600 | 850 | Yes |
| Exp_023 | 35 | 50 | 50 | 1.50 | 600 | 600 | 850 | Yes |
| Exp_024 | 50 | 65 | 65 | 1.50 | 600 | 600 | 850 | Yes |
| Exp_025 | 20 | 35 | 35 | 0.66 | 750 | 750 | 1000 | Yes |
| Exp_026 | 35 | 50 | 50 | 0.66 | 750 | 750 | 1000 | Yes |
| Exp_027 | 50 | 65 | 65 | 0.66 | 750 | 750 | 1000 | Yes |
| Exp_028 | 20 | 35 | 35 | 0.90 | 750 | 750 | 1000 | Yes |
| Exp_029 | 35 | 50 | 50 | 0.90 | 750 | 750 | 1000 | Yes |
| Exp_030 | 50 | 65 | 65 | 0.90 | 750 | 750 | 1000 | Yes |
| Exp_031 | 20 | 35 | 35 | 1.15 | 750 | 750 | 1000 | Yes |
| Exp_032 | 35 | 50 | 50 | 1.15 | 750 | 750 | 1000 | Yes |
| Exp_033 | 50 | 65 | 65 | 1.15 | 750 | 750 | 1000 | Yes |
| Exp_034 | 20 | 35 | 35 | 1.50 | 750 | 750 | 1000 | Yes |
| Exp_035 | 35 | 50 | 50 | 1.50 | 750 | 750 | 1000 | Yes |
| Exp_036 | 50 | 65 | 65 | 1.50 | 750 | 750 | 1000 | Yes |
| Exp_201 | 20 | 35 | 35 | 0.66 | 450 | 450 | 700 | No |
| Exp_202 | 35 | 50 | 50 | 0.66 | 450 | 450 | 700 | No |
| Exp_203 | 50 | 65 | 65 | 0.66 | 450 | 450 | 700 | No |
| Exp_204 | 20 | 35 | 35 | 0.90 | 450 | 450 | 700 | No |
| Exp_205 | 35 | 50 | 50 | 0.90 | 450 | 450 | 700 | No |
| Exp_206 | 50 | 65 | 65 | 0.90 | 450 | 450 | 700 | No |
| Exp_207 | 20 | 35 | 35 | 1.15 | 450 | 450 | 700 | No |
| Exp_208 | 35 | 50 | 50 | 1.15 | 450 | 450 | 700 | No |
| Exp_209 | 50 | 65 | 65 | 1.15 | 450 | 450 | 700 | No |
| Exp_210 | 20 | 35 | 35 | 1.50 | 450 | 450 | 700 | No |
| Exp_211 | 35 | 50 | 50 | 1.50 | 450 | 450 | 700 | No |
| Exp_212 | 50 | 65 | 65 | 1.50 | 450 | 450 | 700 | No |
| Exp_213 | 20 | 35 | 35 | 0.66 | 600 | 600 | 850 | No |
| Exp_214 | 35 | 50 | 50 | 0.66 | 600 | 600 | 850 | No |
| Exp_215 | 50 | 65 | 65 | 0.66 | 600 | 600 | 850 | No |
| Exp_216 | 20 | 35 | 35 | 0.90 | 600 | 600 | 850 | No |
| Exp_217 | 35 | 50 | 50 | 0.90 | 600 | 600 | 850 | No |
| Exp_218 | 50 | 65 | 65 | 0.90 | 600 | 600 | 850 | No |
| Exp_219 | 20 | 35 | 35 | 1.15 | 600 | 600 | 850 | No |
| Exp_220 | 35 | 50 | 50 | 1.15 | 600 | 600 | 850 | No |
| Exp_221 | 50 | 65 | 65 | 1.15 | 600 | 600 | 850 | No |
| Exp_222 | 20 | 35 | 35 | 1.50 | 600 | 600 | 850 | No |
| Exp_223 | 35 | 50 | 50 | 1.50 | 600 | 600 | 850 | No |
| Exp_224 | 50 | 65 | 65 | 1.50 | 600 | 600 | 850 | No |
| Exp_225 | 20 | 35 | 35 | 0.66 | 750 | 750 | 1000 | No |
| Exp_226 | 35 | 50 | 50 | 0.66 | 750 | 750 | 1000 | No |
| Exp_227 | 50 | 65 | 65 | 0.66 | 750 | 750 | 1000 | No |
| Exp_228 | 20 | 35 | 35 | 0.90 | 750 | 750 | 1000 | No |
| Exp_229 | 35 | 50 | 50 | 0.90 | 750 | 750 | 1000 | No |
| Exp_230 | 50 | 65 | 65 | 0.90 | 750 | 750 | 1000 | No |
| Exp_231 | 20 | 35 | 35 | 1.15 | 750 | 750 | 1000 | No |
| Exp_232 | 35 | 50 | 50 | 1.15 | 750 | 750 | 1000 | No |
| Exp_233 | 50 | 65 | 65 | 1.15 | 750 | 750 | 1000 | No |
| Exp_234 | 20 | 35 | 35 | 1.50 | 750 | 750 | 1000 | No |
| Exp_235 | 35 | 50 | 50 | 1.50 | 750 | 750 | 1000 | No |
| Exp_236 | 50 | 65 | 65 | 1.50 | 750 | 750 | 1000 | No |

# Data Analysis of Unmitigated Simulations with Honeywell Sensor/Tracker Models: DAA Alerting Performance Metrics

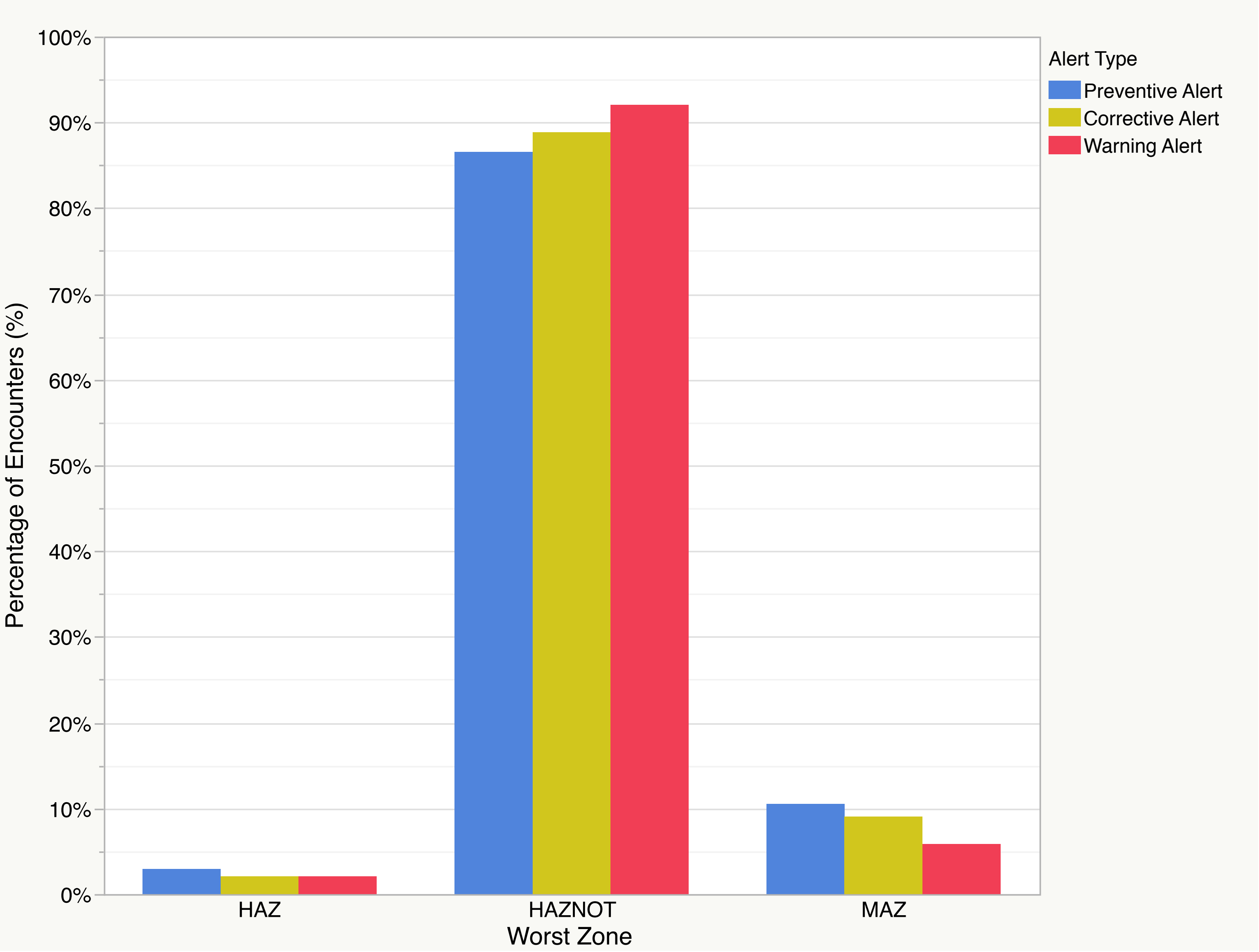
# Encounter Definition

- An encounter initialized on 25 nm horizontal x 6000 ft vertical cylinder,

AND

- The intruders are predicted to be within 10 nm x 2000 ft cylinder in the next 5 minutes look-ahead time window based on dead-reckoning trajectory prediction.

# Analysis of Encounter Set
## (Proportion of Worst Zone By Each Alert Type)



# Analysis for DAA Corrective Alerts

# Experiment Design

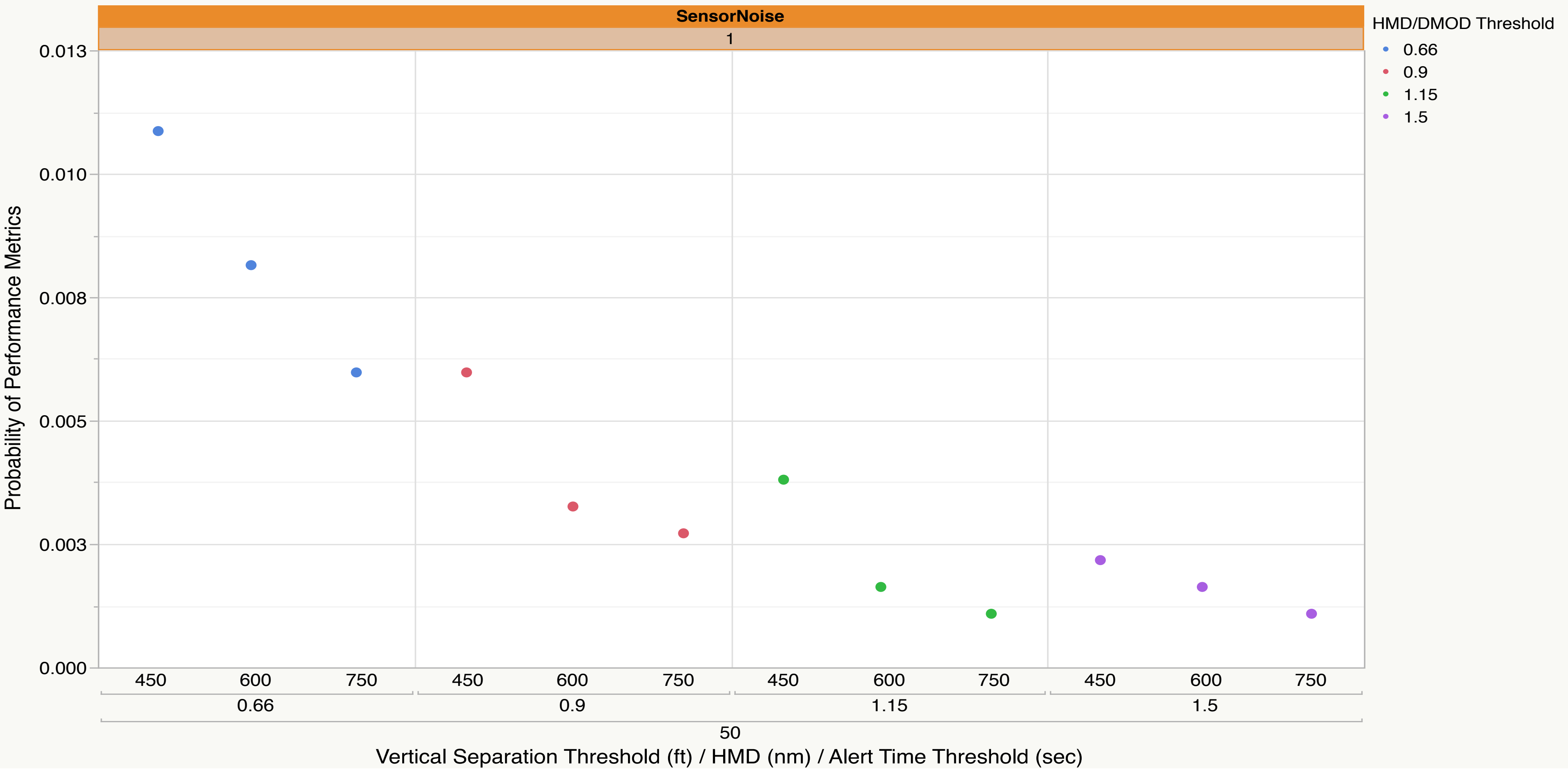
| Independent Factor | Levels for Each Factor | | |
|---|---|---|---|
| Alerting Time Threshold (sec): Predicted Time to Loss of Well-Clear (LoWC) | Alert Type | | |
| | Warning Alert | Corrective Alert | Preventive Alert |
| | 20 | 35 | 35 |
| | 35 | 50 | 50 |
| | 50 | 65 | 65 |
| HMD/DMOD (nm) | Same For All Alert Types<br>0.66, 0.90, 1.15, 1.5 nm | | |
| Vertical Separation Threshold (ft) | 450 | 450 | 700 |
| | 600 | 600 | 850 |
| | 750 | 750 | 1000 |
| Sensor Uncertainty | 0: No Sensor Uncertainty<br>1: Sensor Uncertainty | | |

* Total 72 runs of unmitigated simulations = 3 X 4 X 3 X 2

## Performance Metrics Analyzing Tracks with HAZ Violation (Alerts Required)

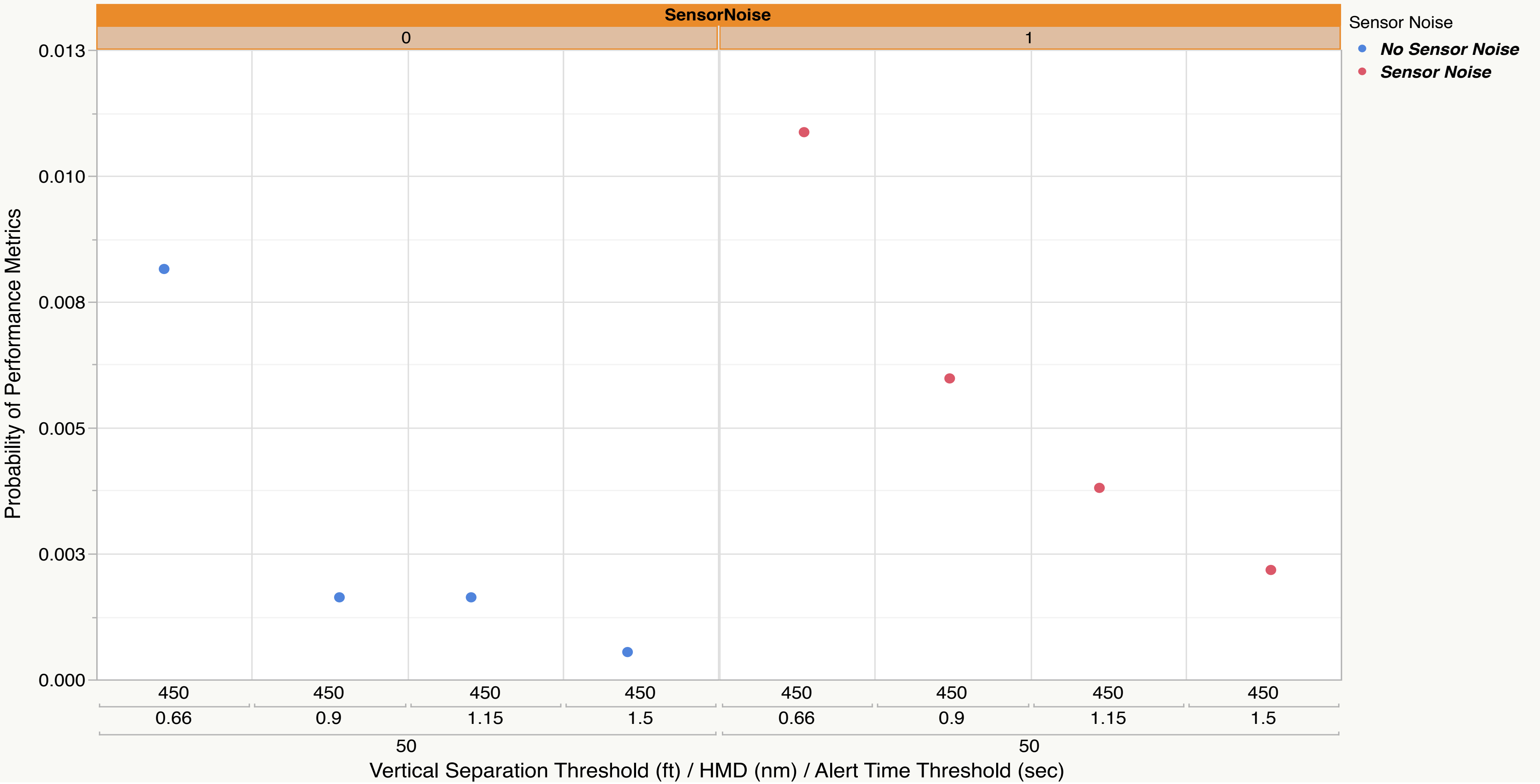
- Probability of Correct Required Alert (CRA)
- Probability of Missed Alert (MA)
- Probability of Late Alert (LA)
- Probability of Short Alert (SA)

# Corrective Missed Alert
## (Effect of HMD/DMOD Threshold)



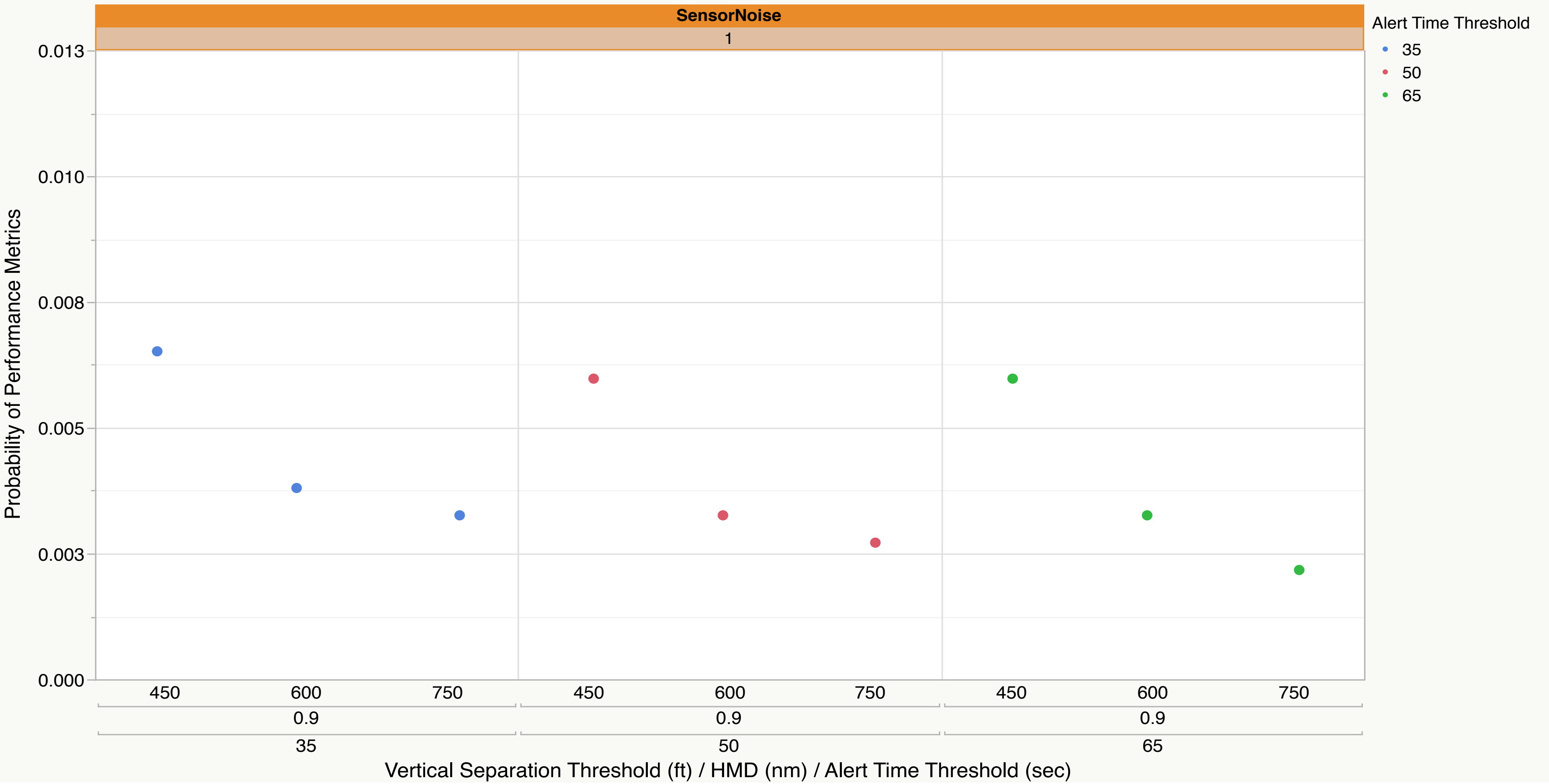

To reduce the P(MA), it would be better to have a larger HMD/DMOD threshold and a larger vertical separation threshold.

# Corrective Missed Alert
## (Effect of Sensor Noise)



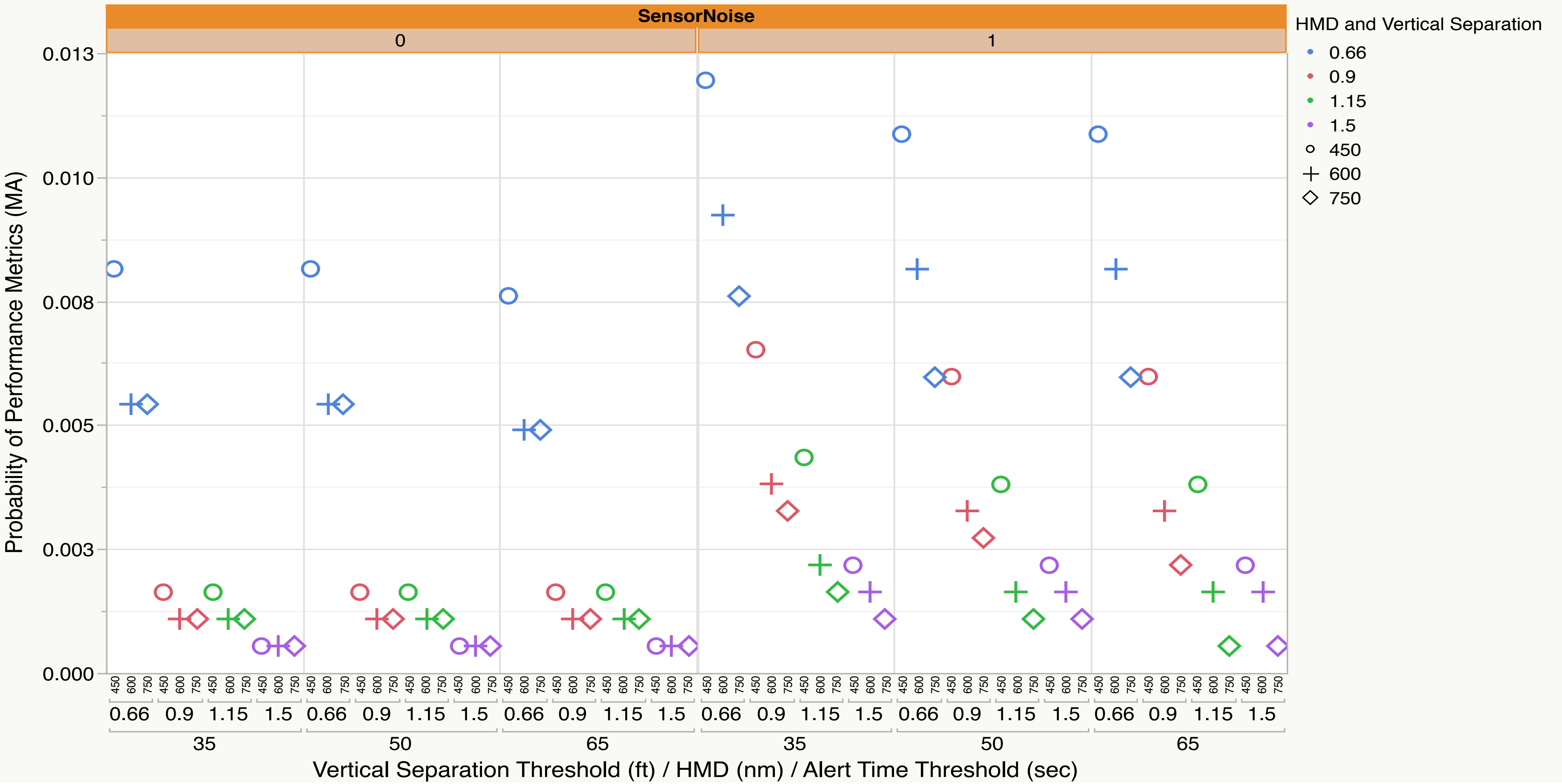

The probability of MA is higher across all HMD/DMOD threshold settings when there is sensor noise, compared to when there is no sensor noise.

# Corrective Missed Alert
## (Effect of Alert Time Threshold)



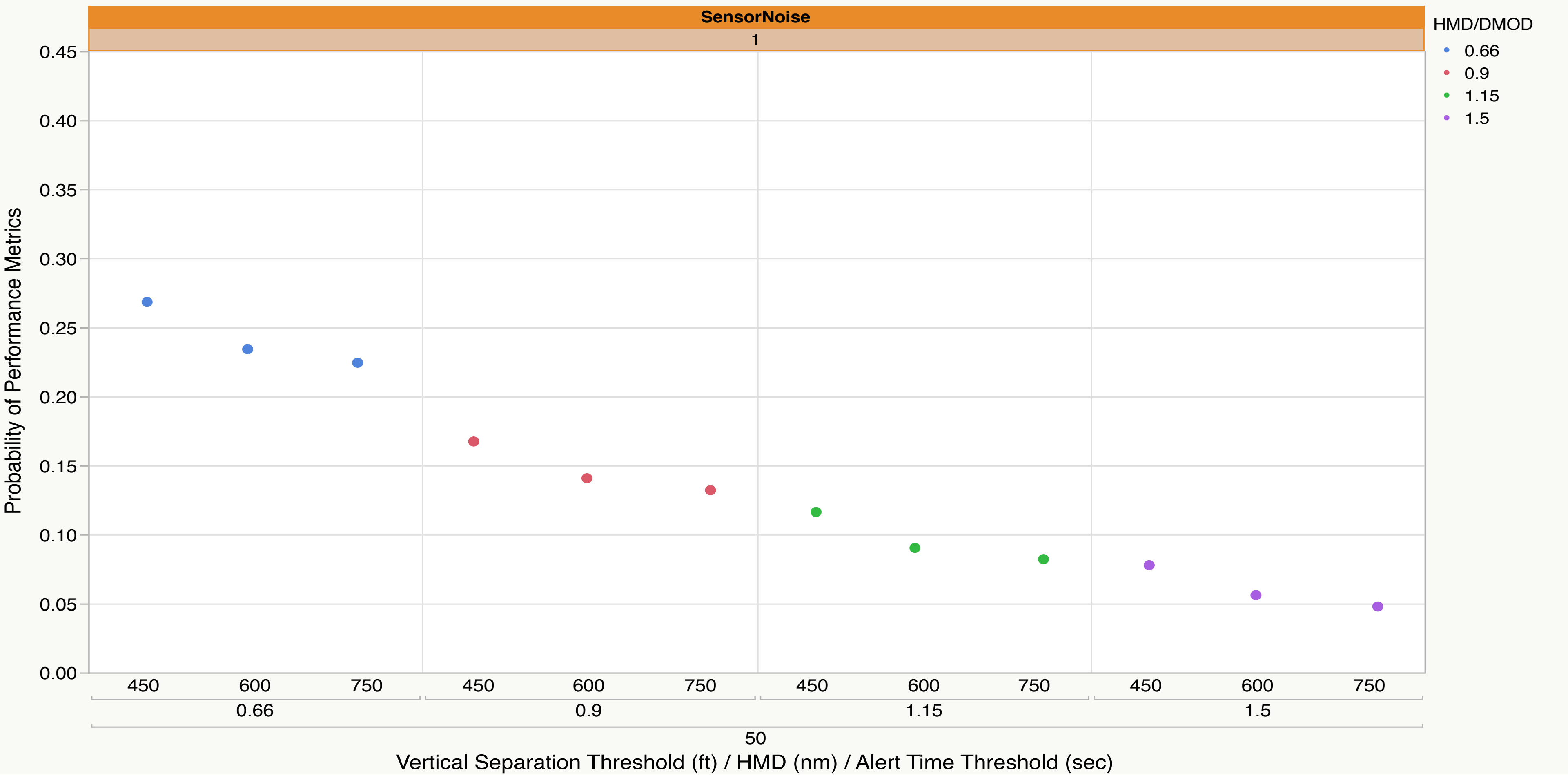

There is no significant effect of DAA alert time threshold on the P(MA).

# Probability of Missed Alert (MA)



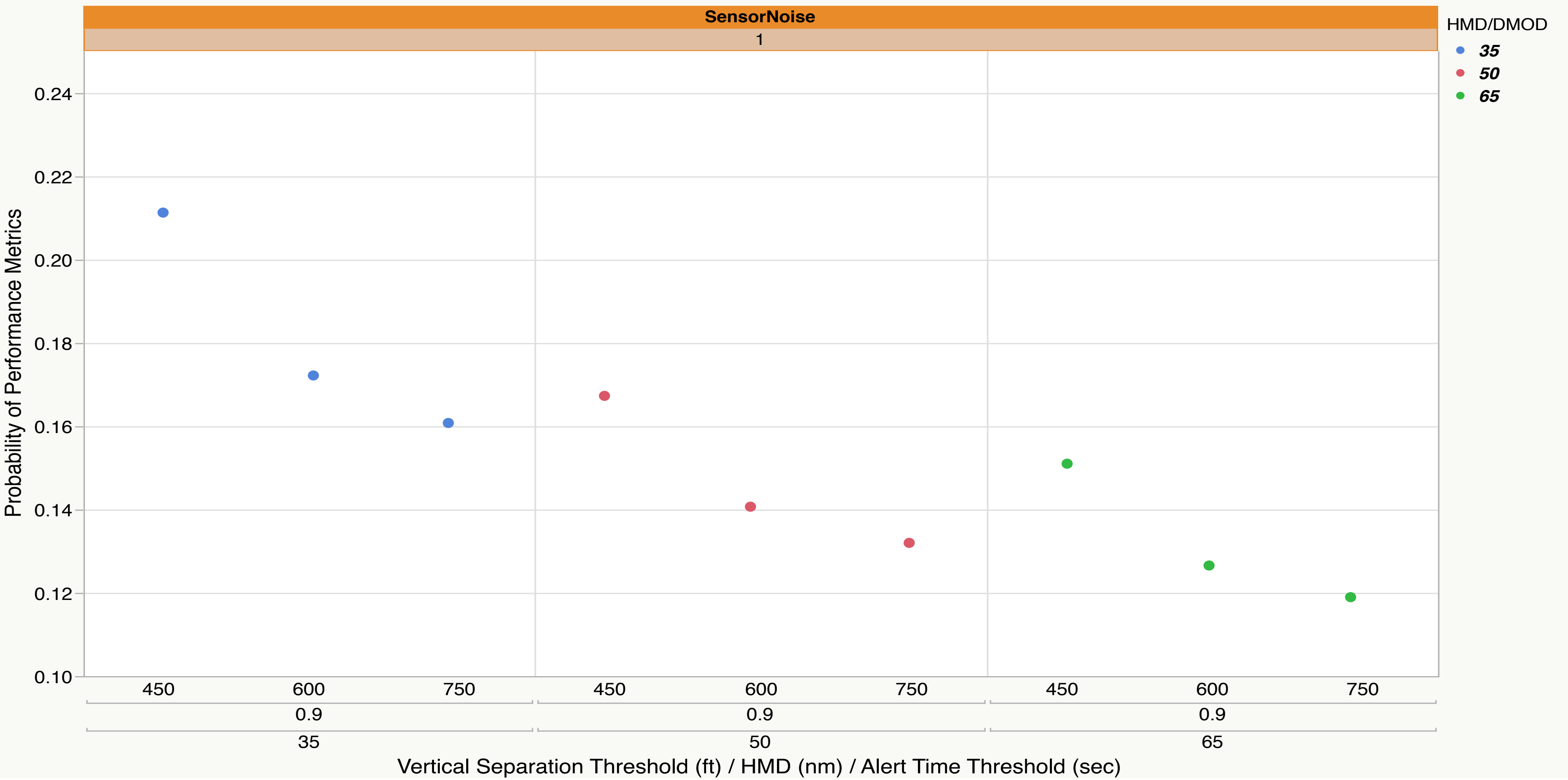

There is a significant effect of HMD and vertical threshold settings and sensor noise on the P(MA). On the other hand, there is no significant effect of alert time threshold on the P(MA).

# Corrective Late Alert
## (Effect of HMD/DMOD)



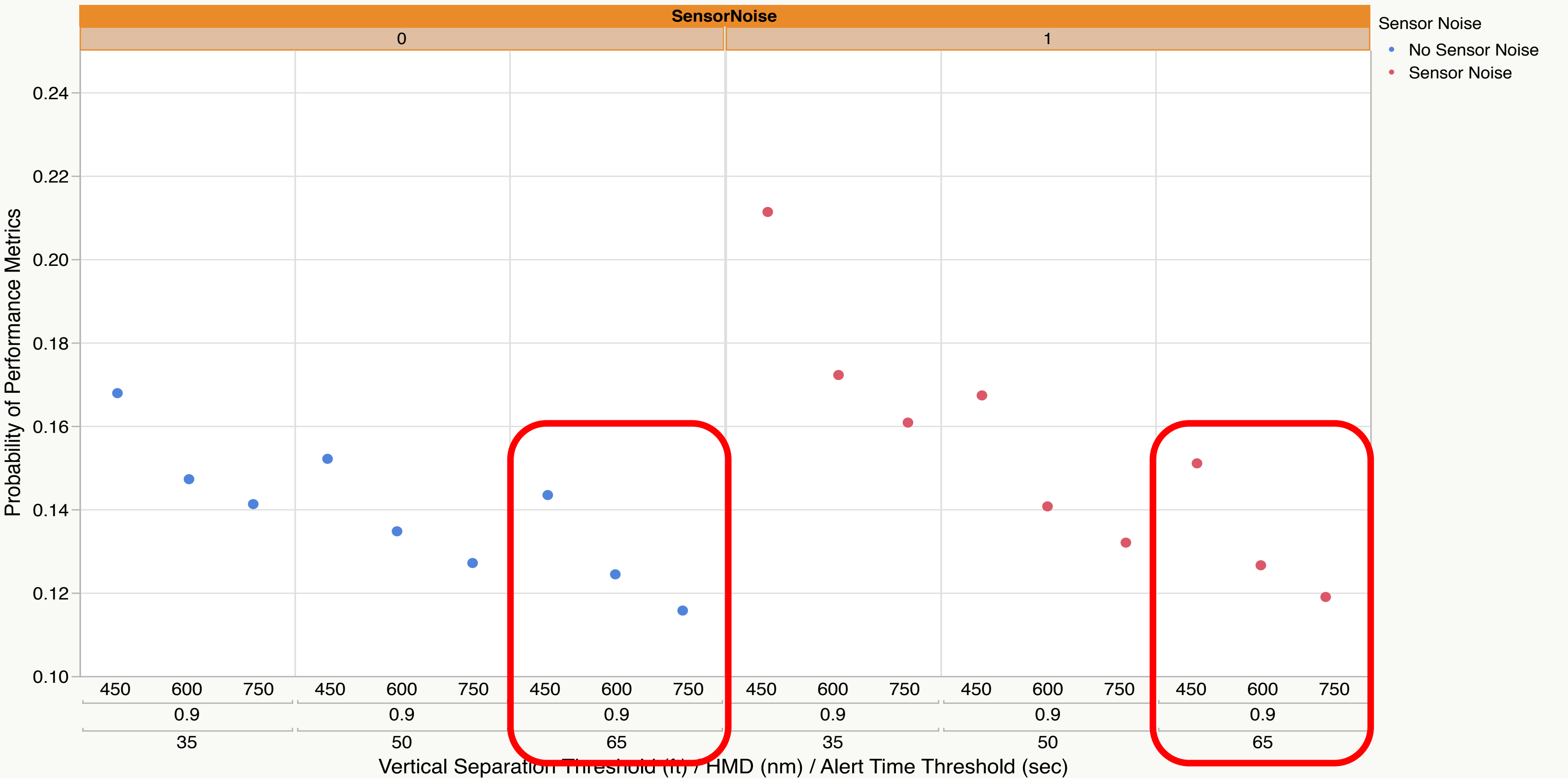

To reduce the P(LA), it would be better to have a larger HMD/DMOD threshold and a larger vertical separation threshold.

# Corrective Late Alert
## (Effect of Alert Time Threshold)



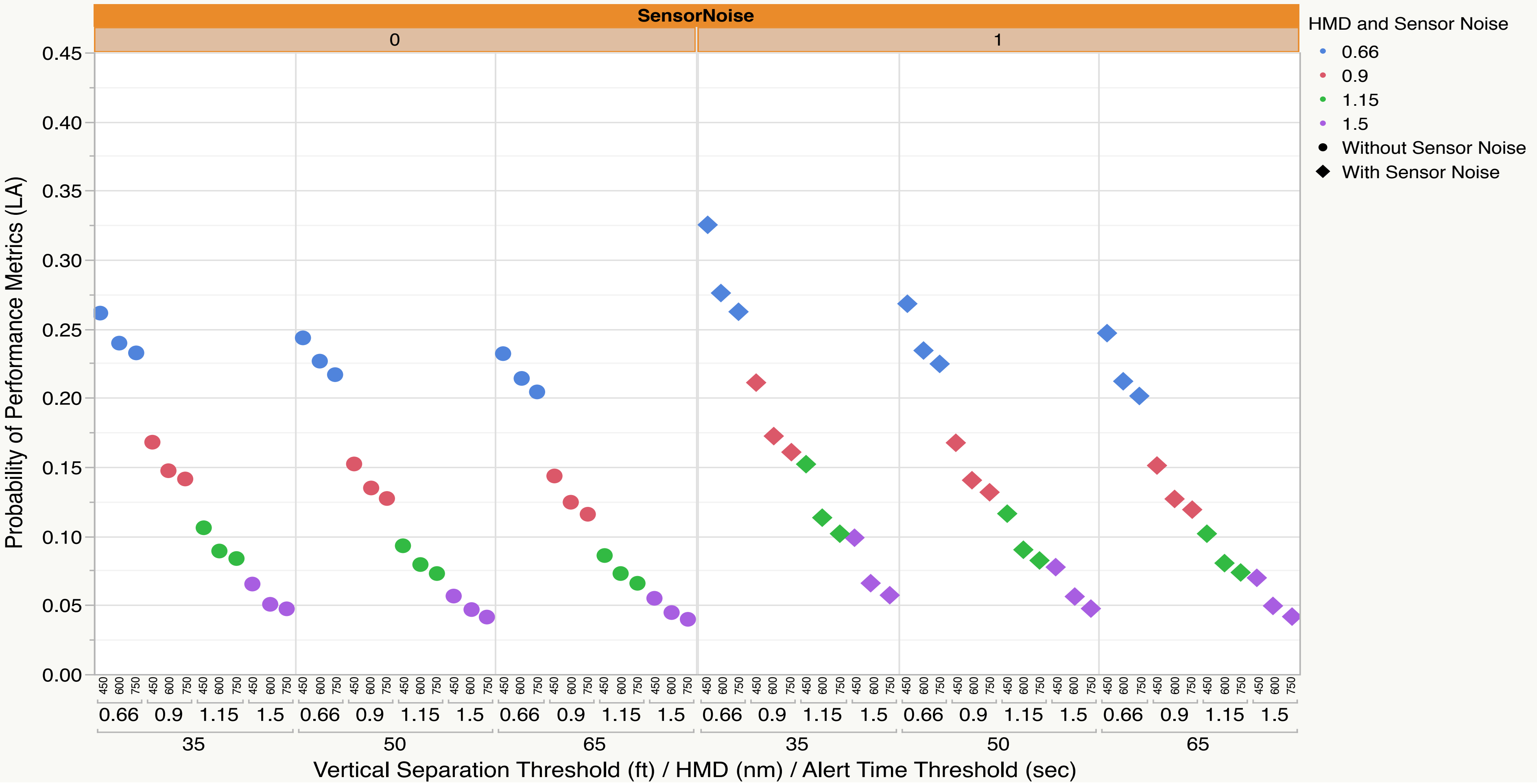

There is a significant effect of DAA alert time threshold on the P(LA).

# Corrective Late Alert
## (Effect of Sensor Noise)



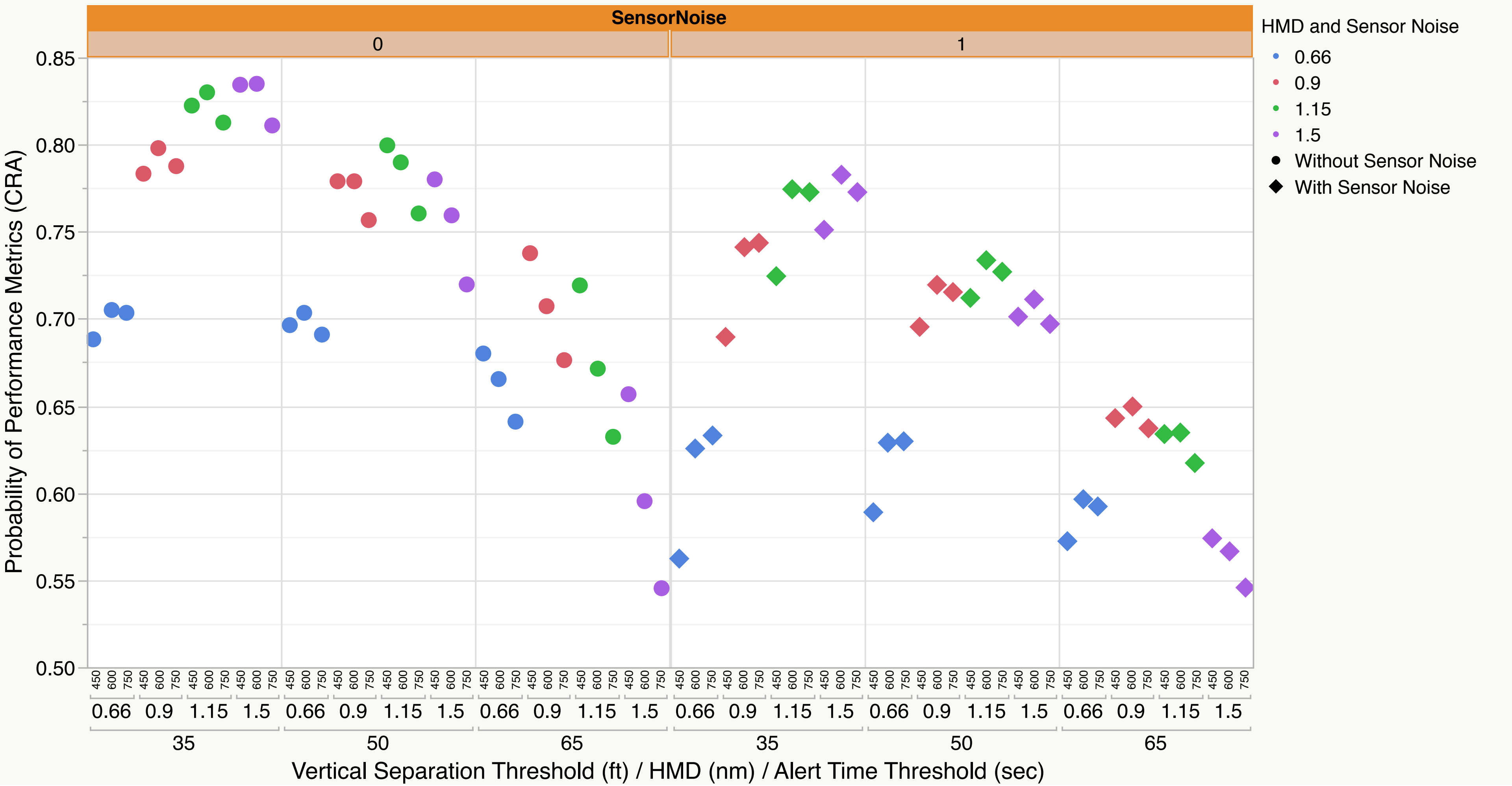

There is a higher probability of Late Alerts when there is sensor noise, compared to there is no sensor noise

# Probability of Late Alert (LA)



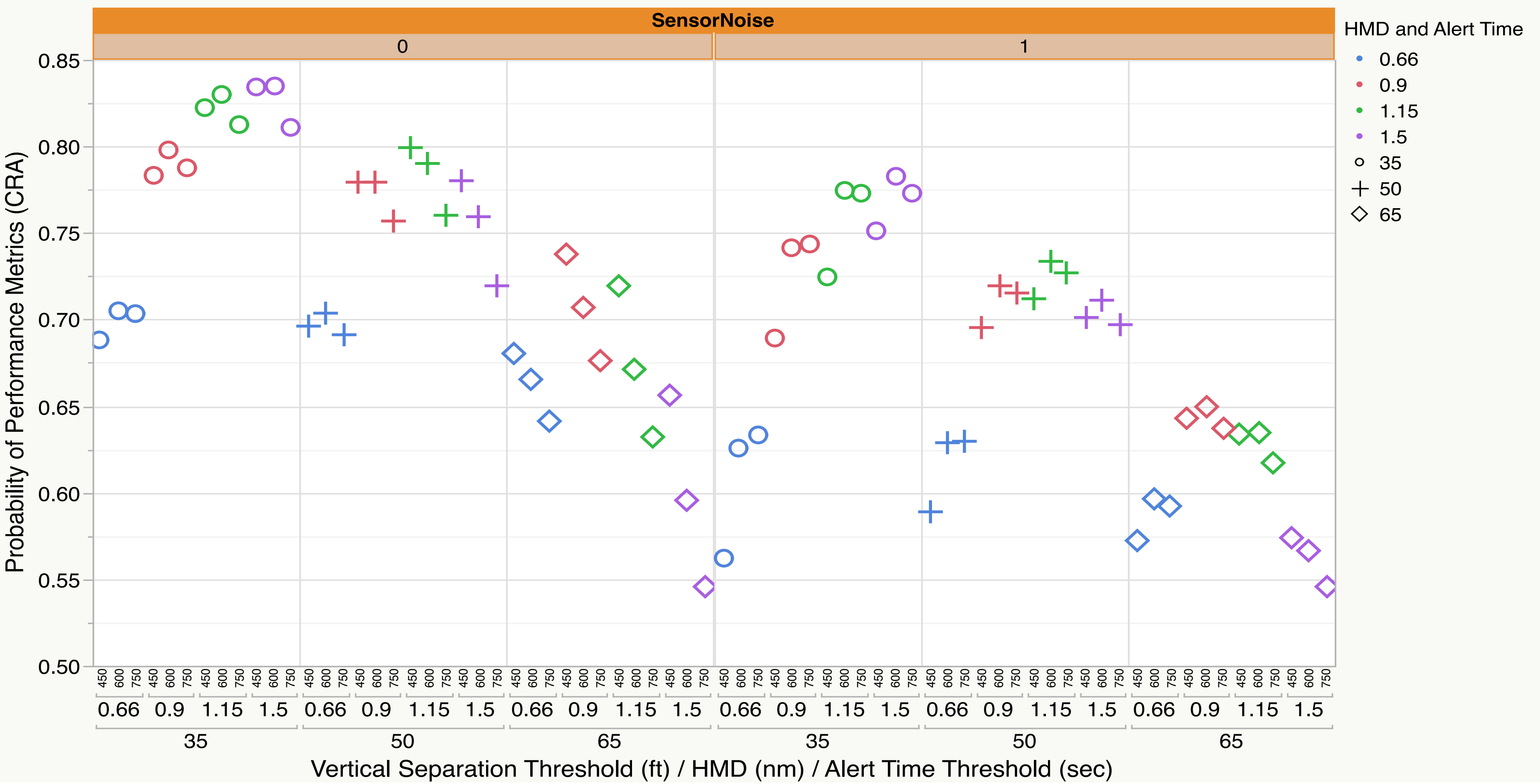

There is a significant effect of HMD/DMOD, vertical separation, and alert time thresholds on the P(LA). On the other hand, there is a less effect of sensor noise on the P(LA).

# Probability of Correct Required Alert (CRA)



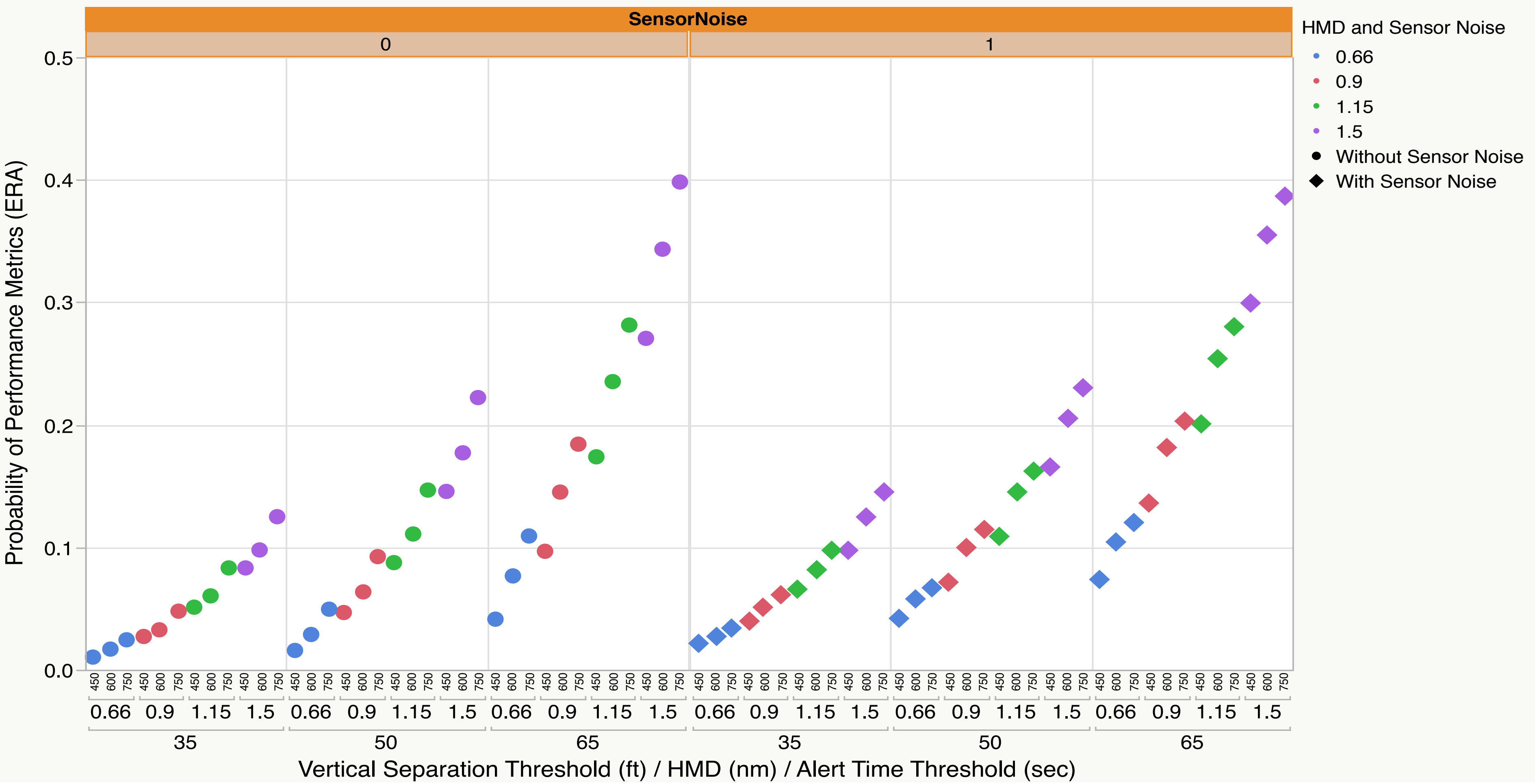

There is a significant effect of alert time threshold, HMD/DMOD, and sensor noise on the P(CRA).

# Probability of Correct Required Alert (CRA)



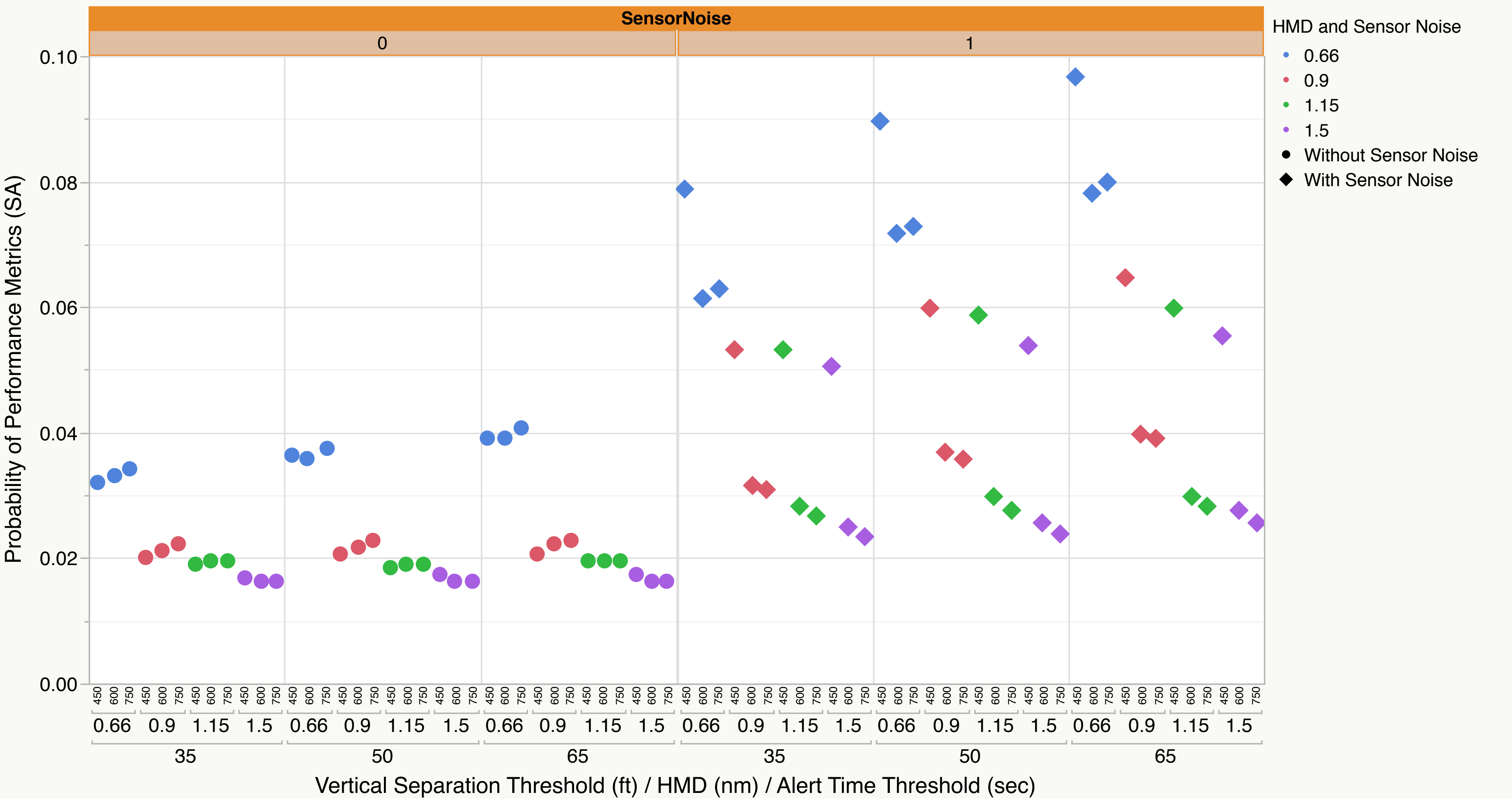

There is a significant effect of alert time threshold, HMD/DMOD, and sensor noise on the P(CRA).

# Probability of Early Required Alert (ERA)

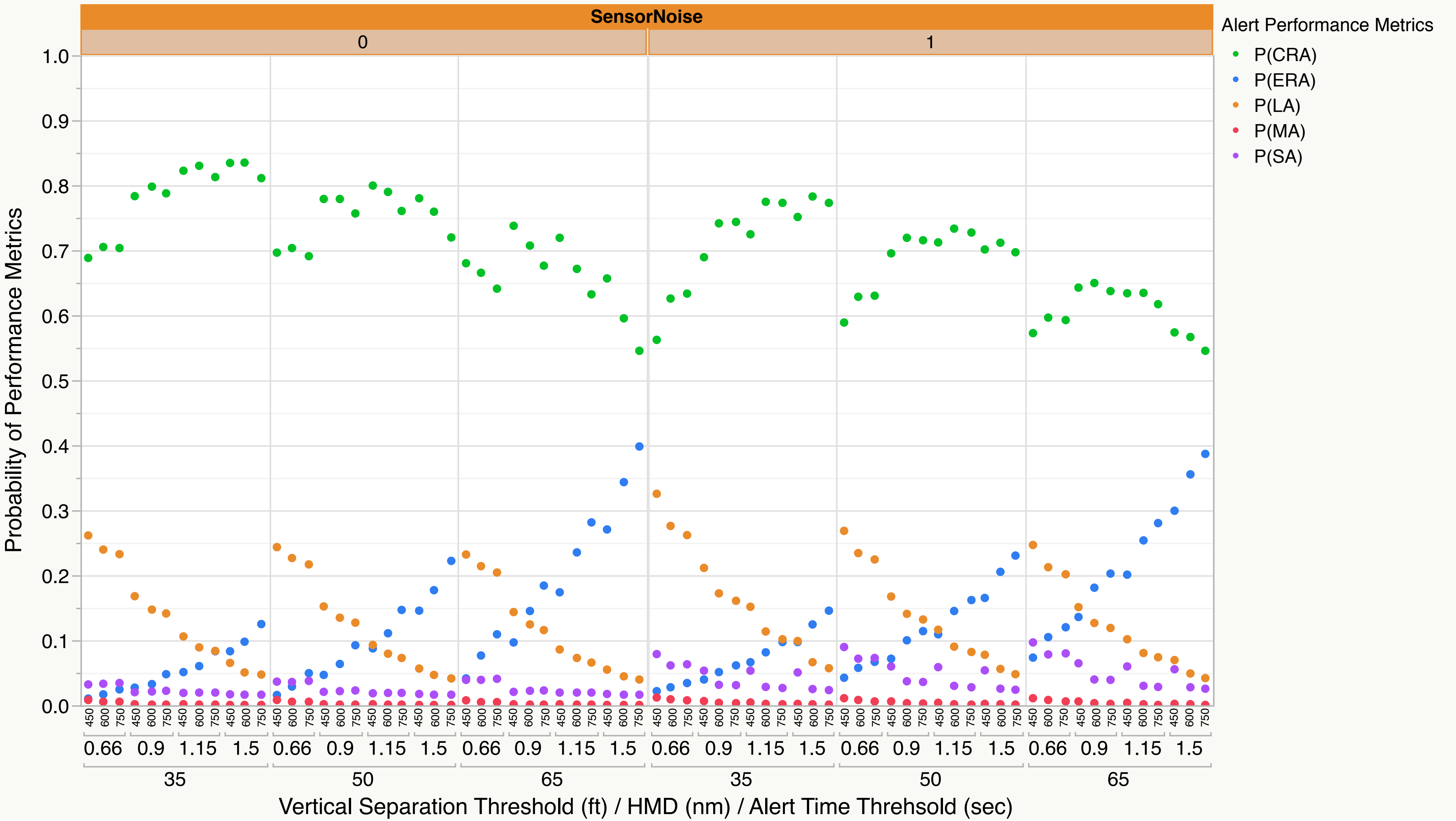



There is a significant effect of HMD/DMOD, alert time threshold, and vertical separation threshold on the P(ERA).

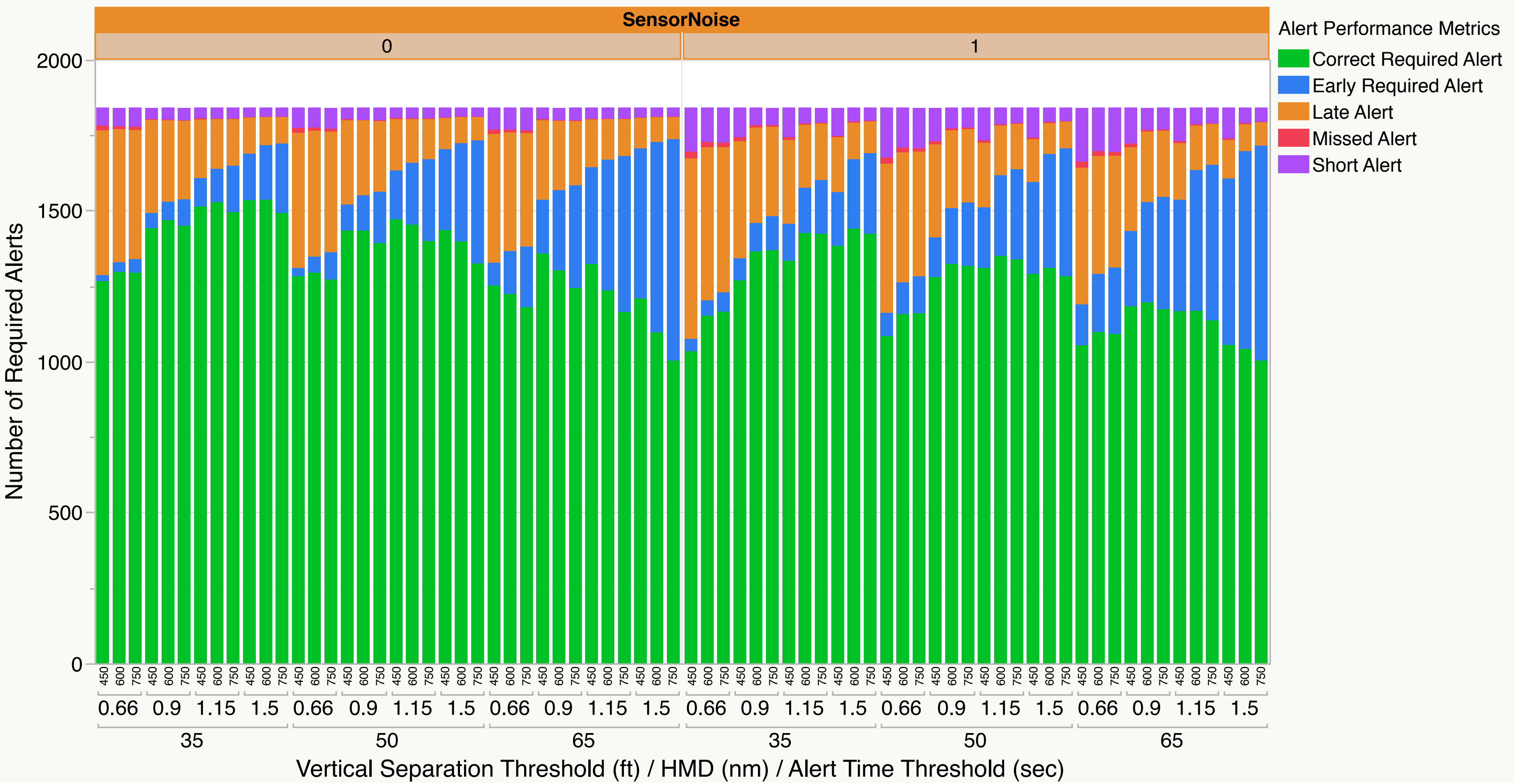
# Probability of Short Alert (SA)



# All Performance Metrics for DAA Required Alerts



# Number of Required Corrective Alerts

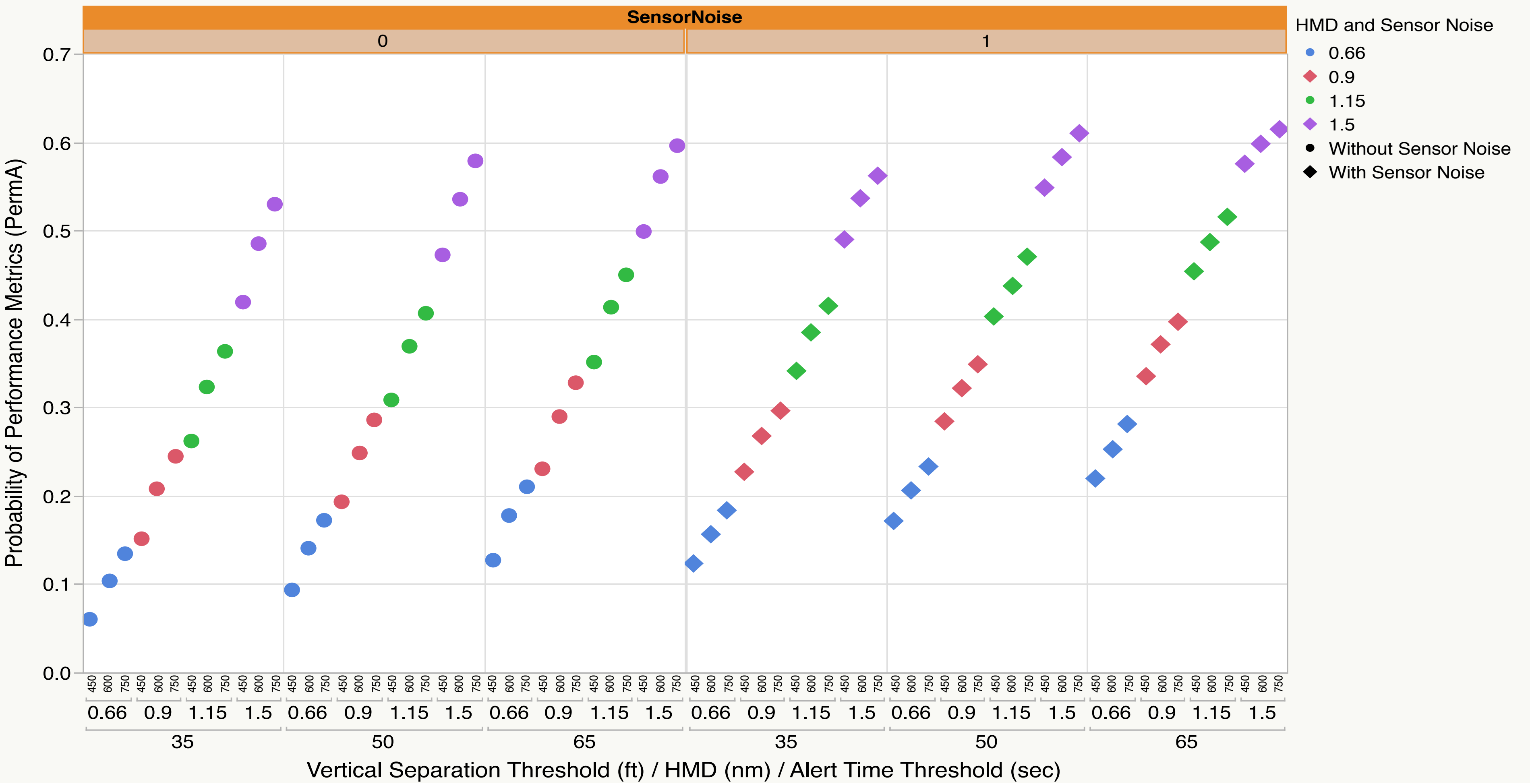


# Analysis for DAA Corrective Alerts

## Performance Metrics Analyzing Tracks with MAZ Violation (Alerts Permissible)

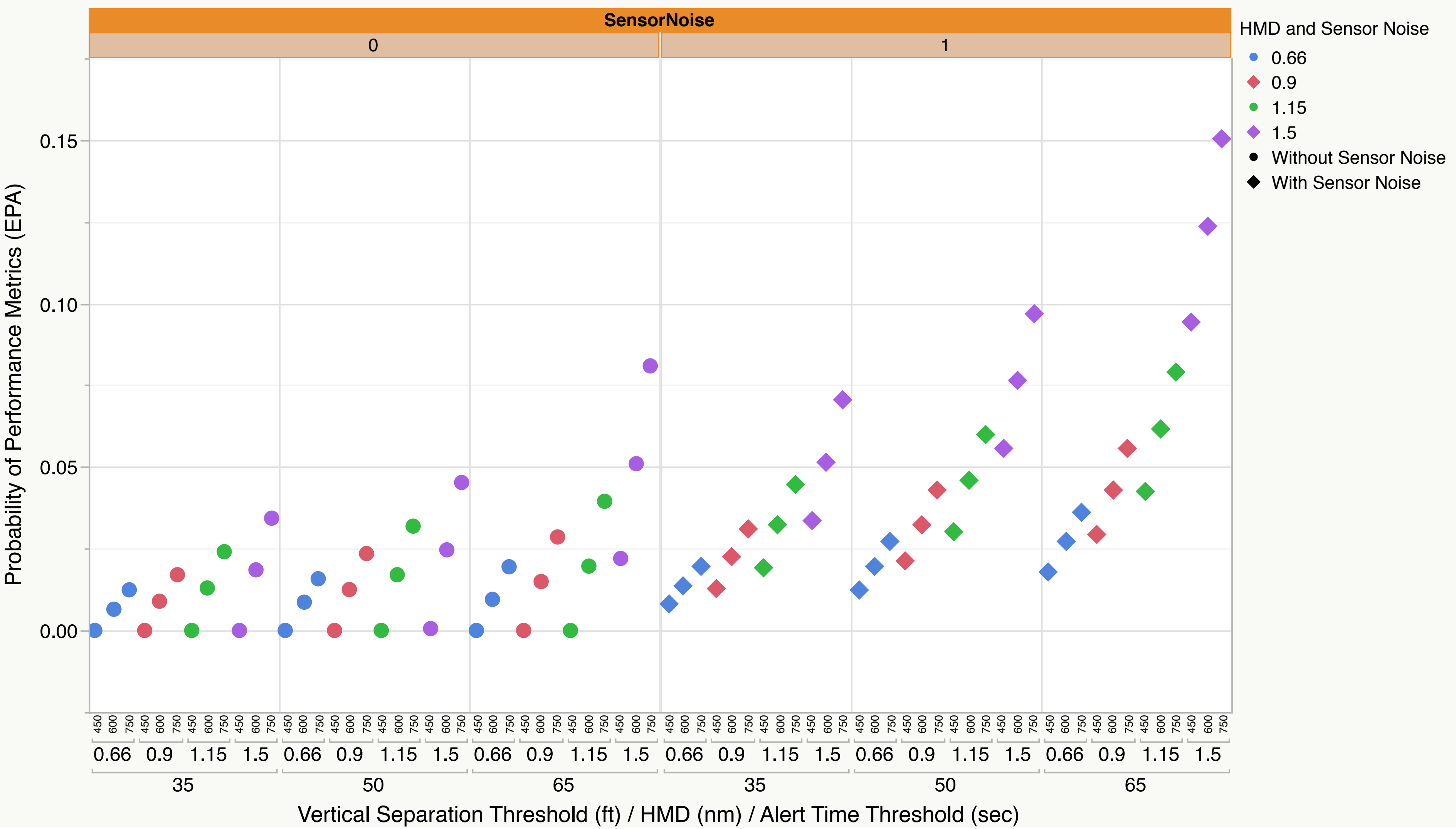
- Probability of Permissible Alert (PermA)
- Probability of Early Permissible Alert (EPA)
- Probability of Permissible Non-Alert (PNA)

# Probability of Permissible Alert




There is a significant effect of HMD/DMOD, alert time threshold, and vertical separation threshold on the P(PermA).

# Probability of Early Permissible Alert

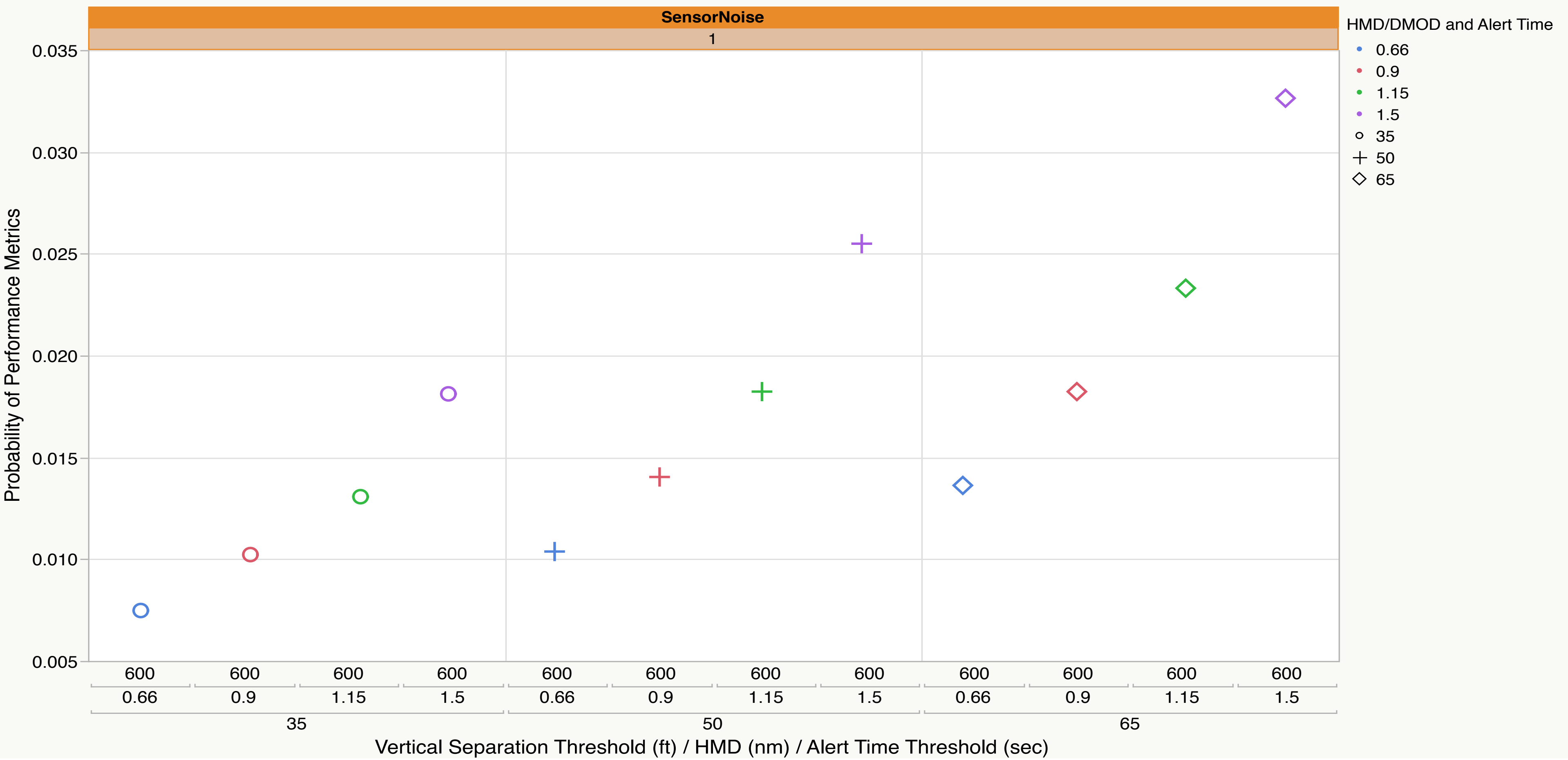


# Analysis for DAA Corrective Alerts

Performance Metrics Analyzing Tracks remaining in Non-Hazard Zone (Alerts Undesirable)

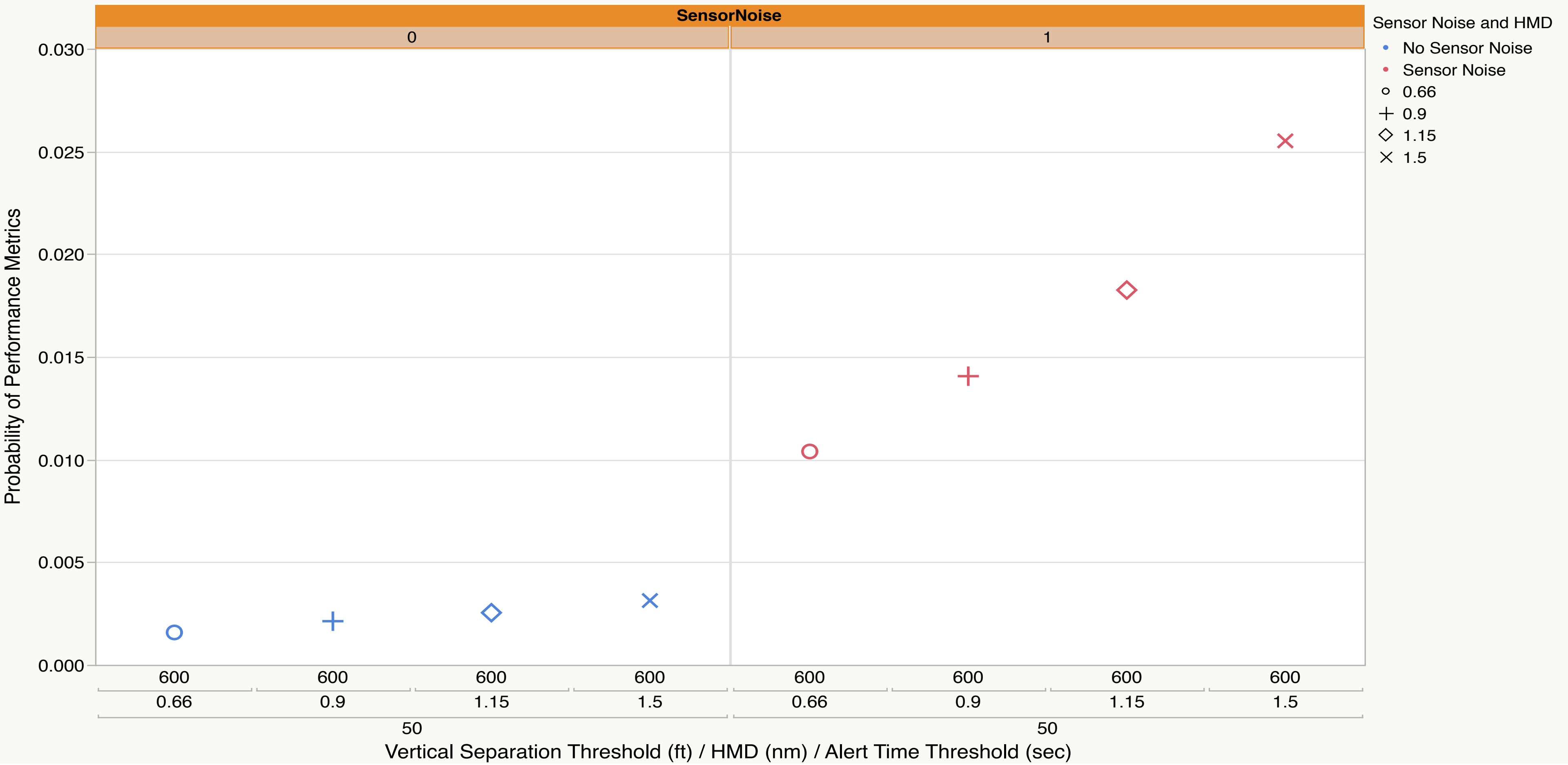
- Probability of Incorrect Alert (IA)
- Probability of Correct Non-Alert (CNA)

# Incorrect Alert
## (Effect of HMD/DMOD and Alert Time)



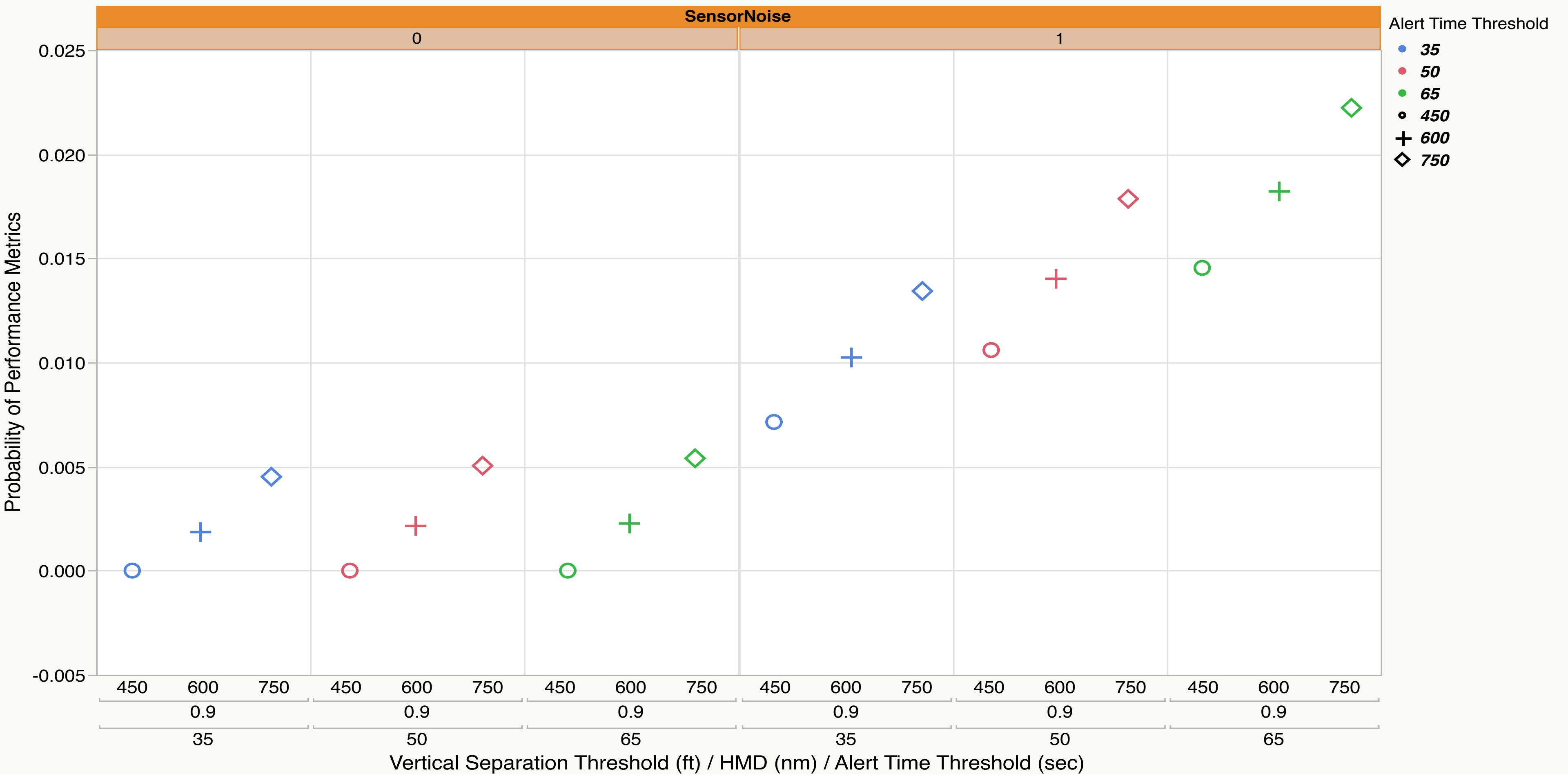

There is a significant effect of HMD/DMOD and alert time thresholds on the P(IA).

# Incorrect Alert (Effect of Sensor Noise and HMD)



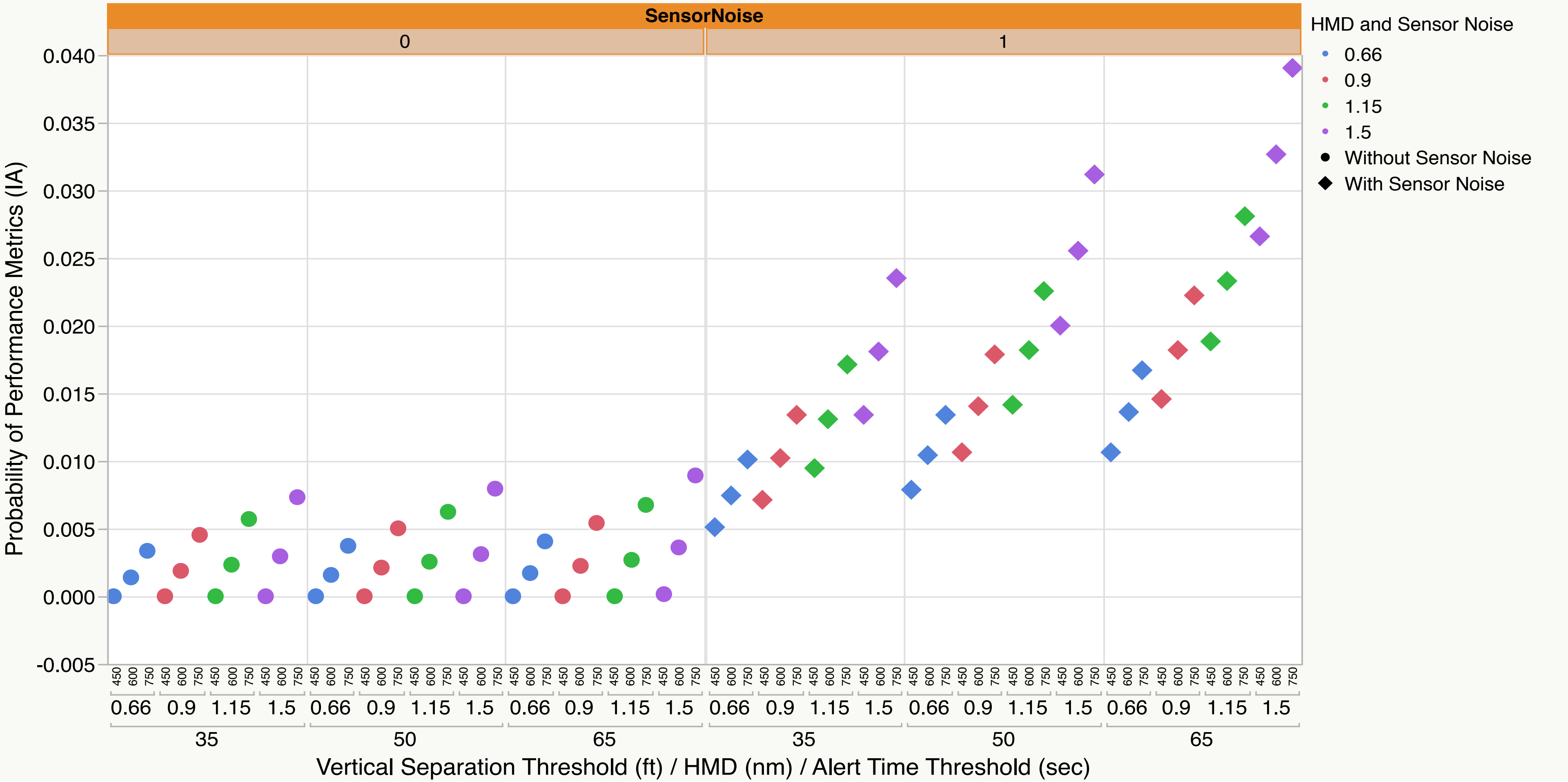

There is a significant effect of sensor noise on the P(IA).

# Incorrect Alert
# (Effect of Vertical Separation and Sensor Noise)



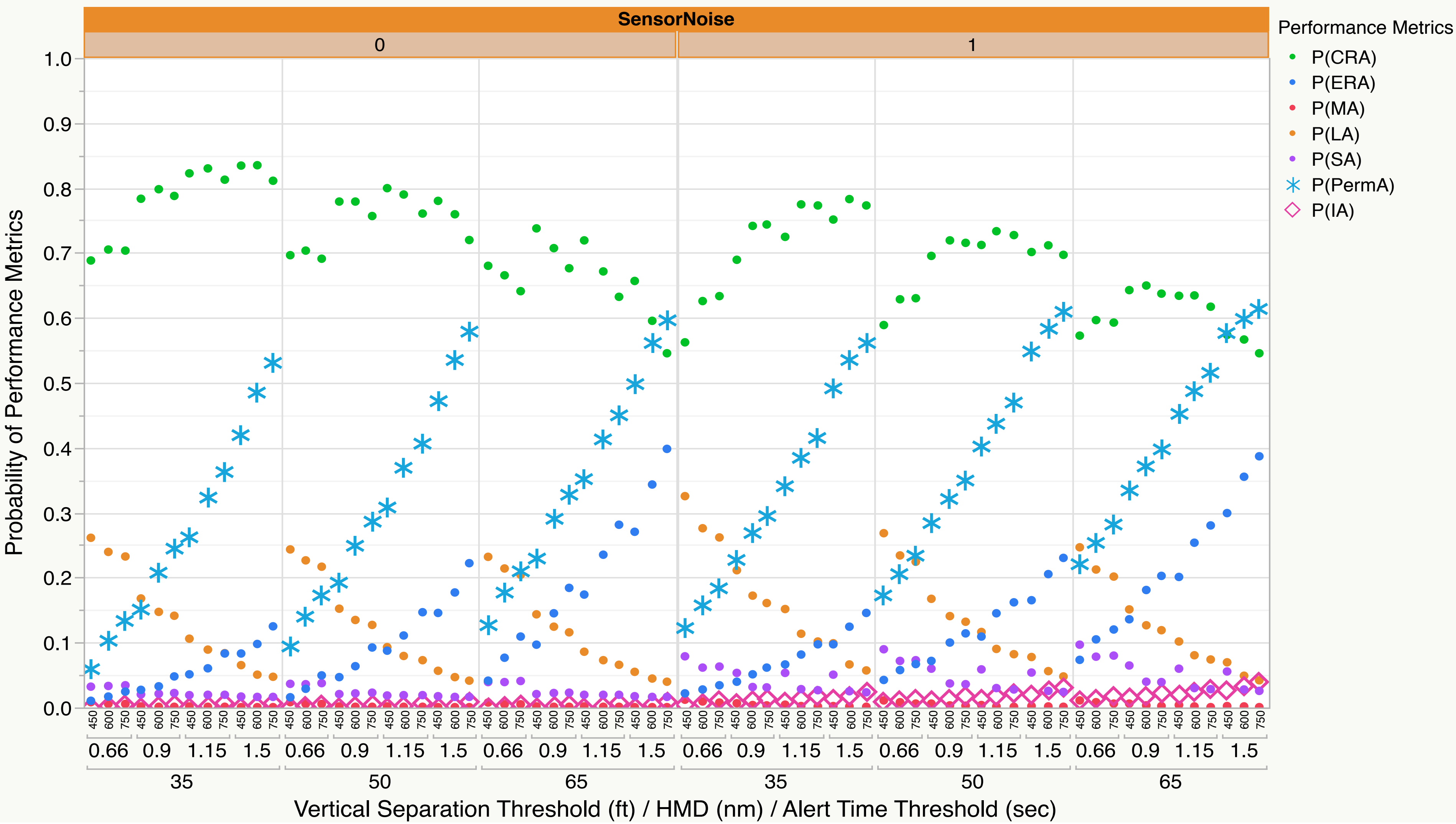

There is a significant effect of vertical separation and alert time thresholds on the P(IA) when there is sensor noise.

# Probability of Incorrect Alert

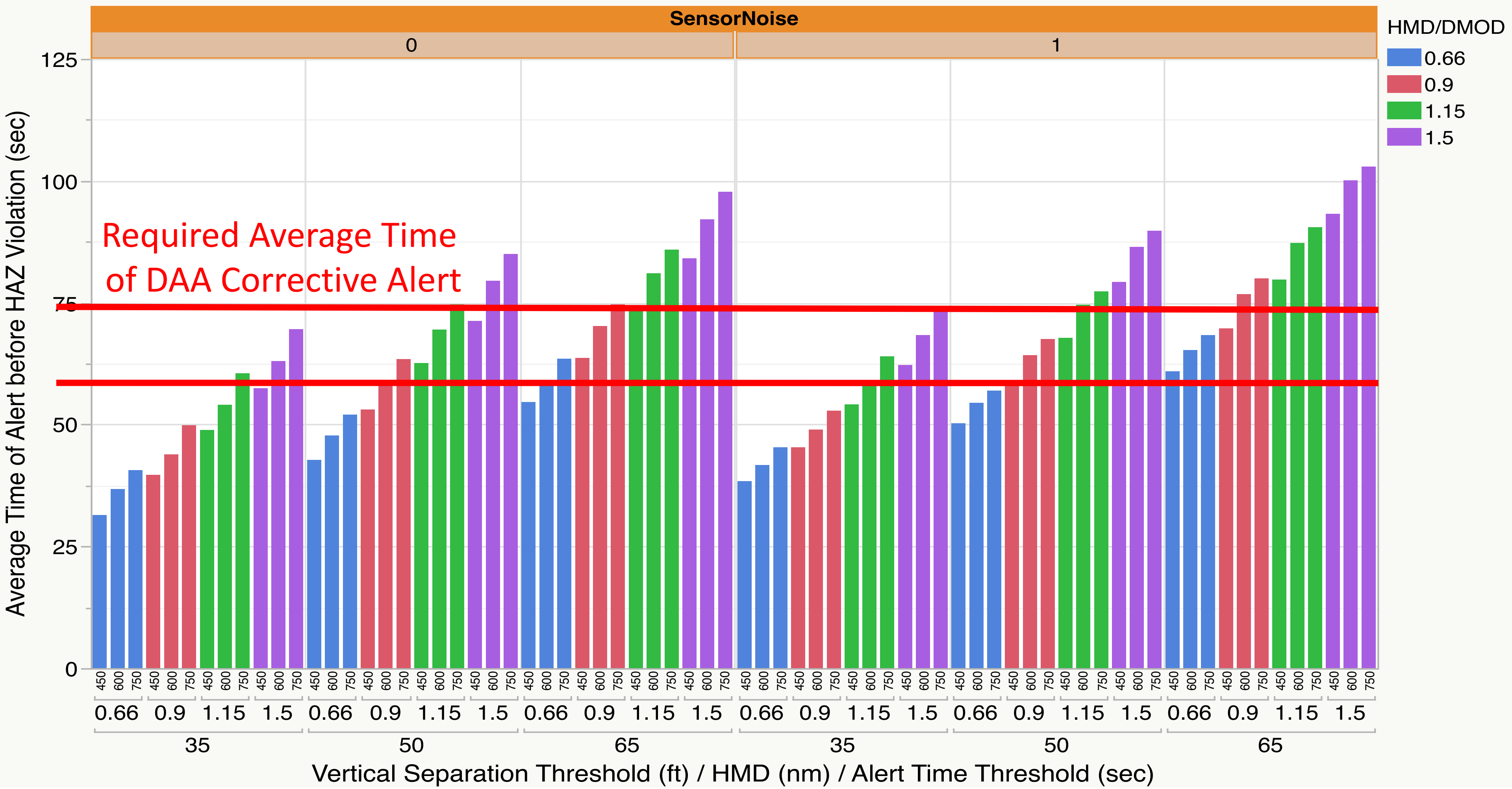



There is a significant effect of Sensor noise, HMD/DMOD, vertical separation, and alert time thresholds on the P(IA).

# All Performance Metrics for DAA Corrective Alerts

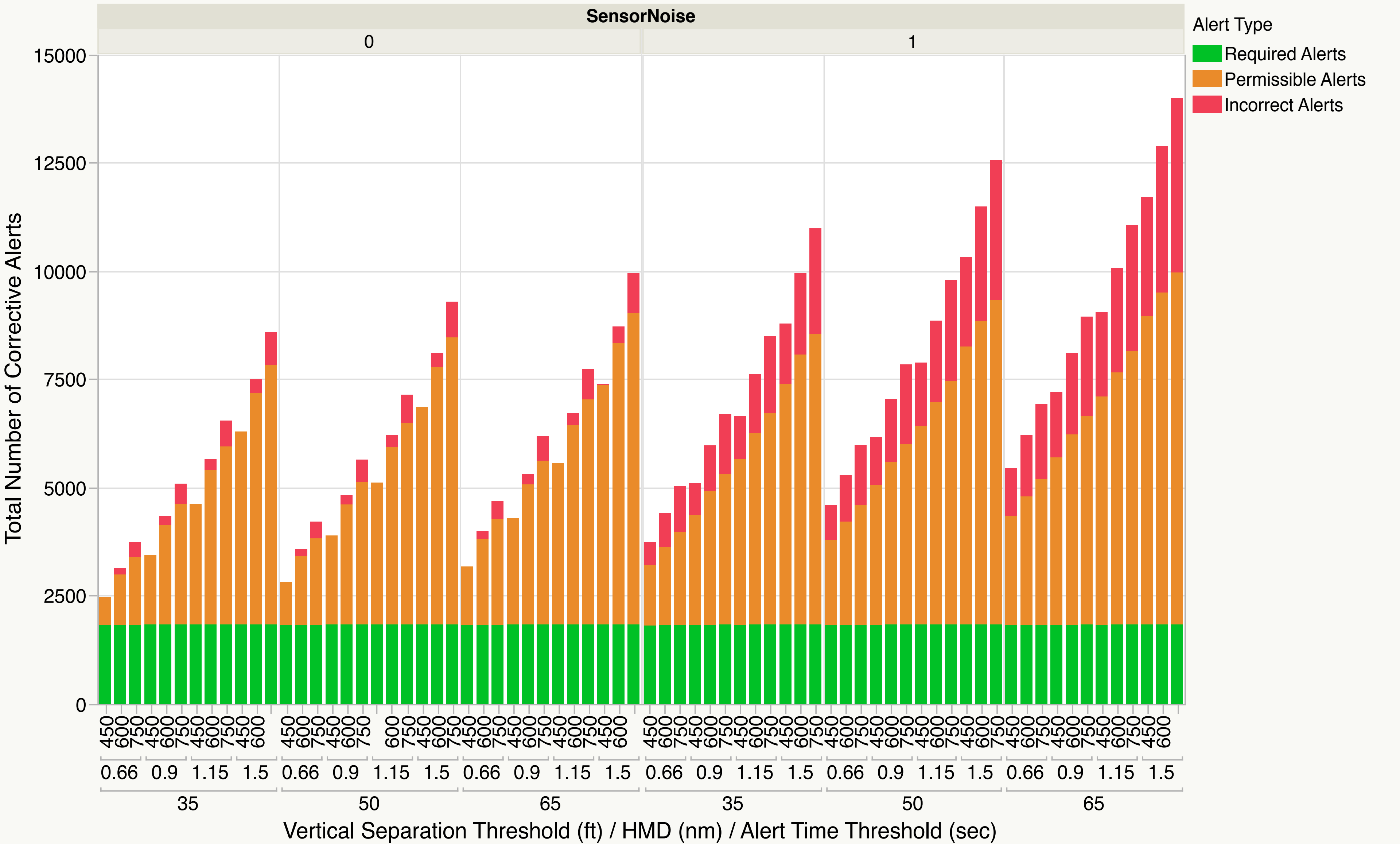


# Average Time of Corrective Alert before HAZ Violation

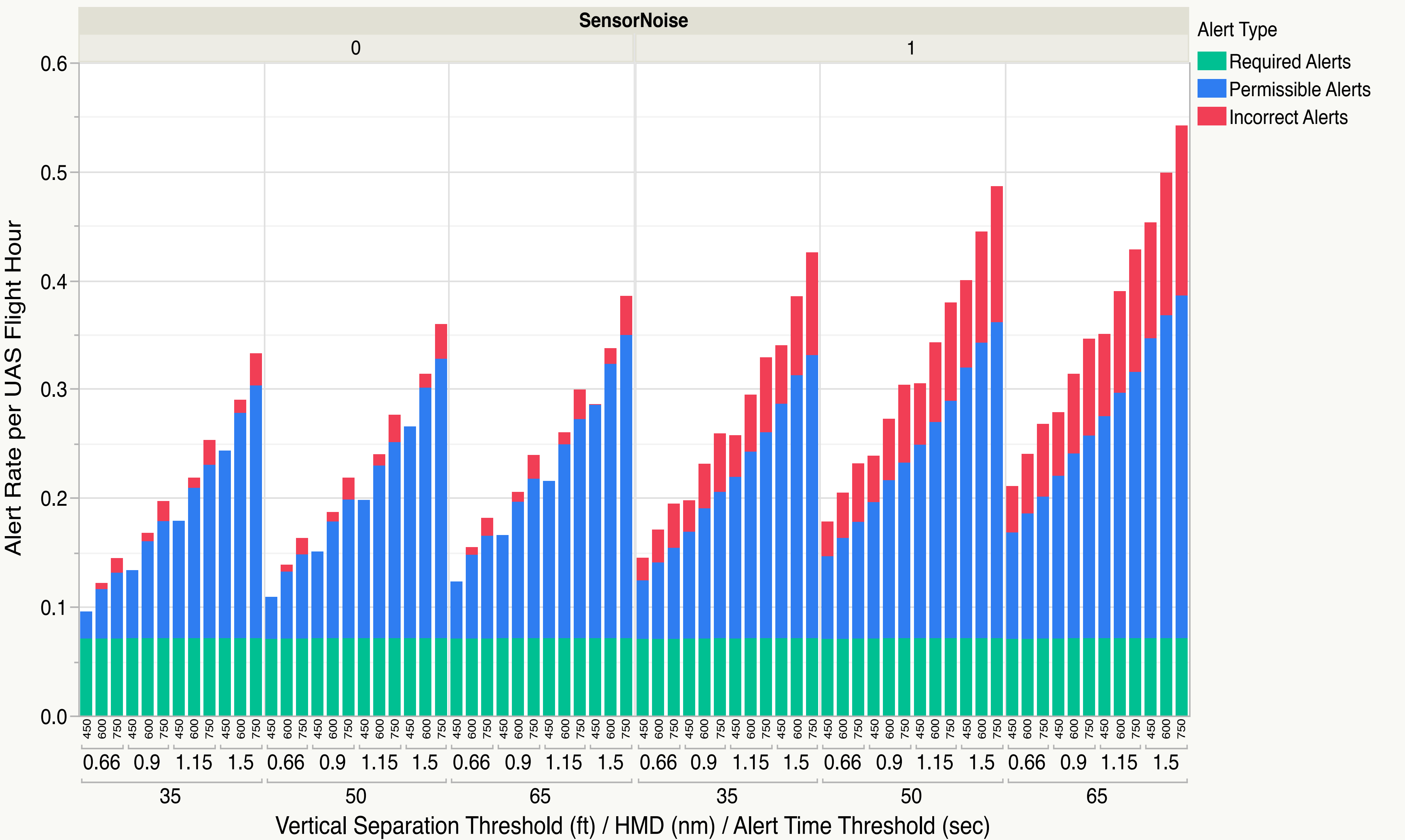



There is a significant effect of HMD/DMOD and Alert Time thresholds on the average time of alert. Vertical separation threshold has an effect on the average time of alert as well.

# Total Number of Corrective Alerts



# DAA Corrective Alert Rate per UAS Flight Hour



# Analysis for DAA Warning Alerts

# Experiment Design

| Independent Factor | Levels for Each Factor | | |
|---|---|---|---|
| Alerting Time Threshold (sec): Predicted Time to Loss of Well-Clear (LoWC) | Alert Type | | |
| | Warning Alert | Corrective Alert | Preventive Alert |
| | 20 | 35 | 35 |
| | 35 | 50 | 50 |
| | 50 | 65 | 65 |
| HMD/DMOD (nm) | Same For All Alert Types<br>0.66, 0.90, 1.15, 1.5 nm | | |
| Vertical Separation Threshold (ft) | 450 | 450 | 700 |
| | 600 | 600 | 850 |
| | 750 | 750 | 1000 |
| Sensor Uncertainty | 0: No Sensor Uncertainty<br>1: Sensor Uncertainty | | |

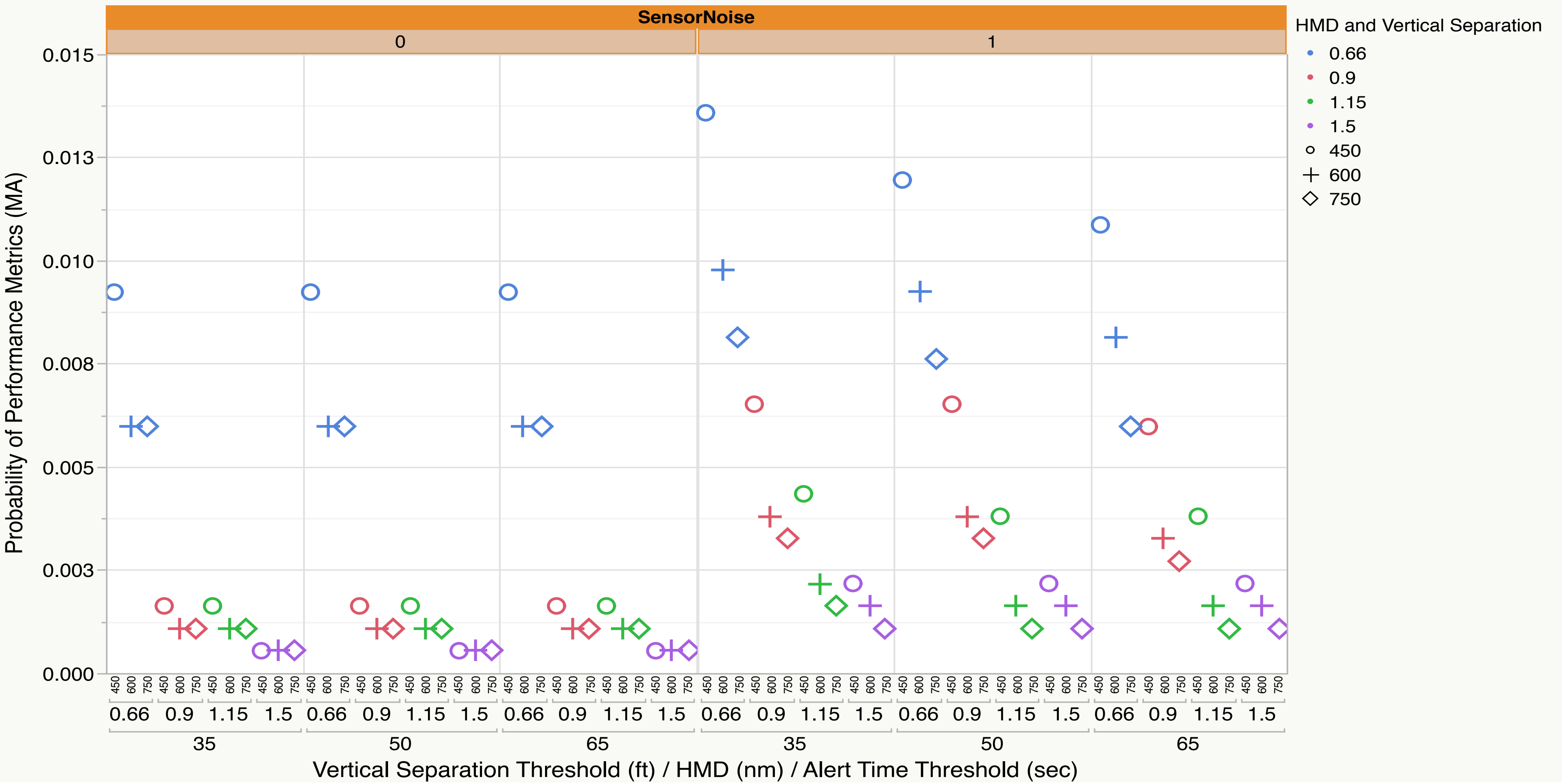
* Total 72 runs of unmitigated simulations = 3 X 4 X 3 X 2

# Analysis for DAA Warning Alerts

## Performance Metrics Analyzing Tracks with HAZ Violation (Alerts Required)

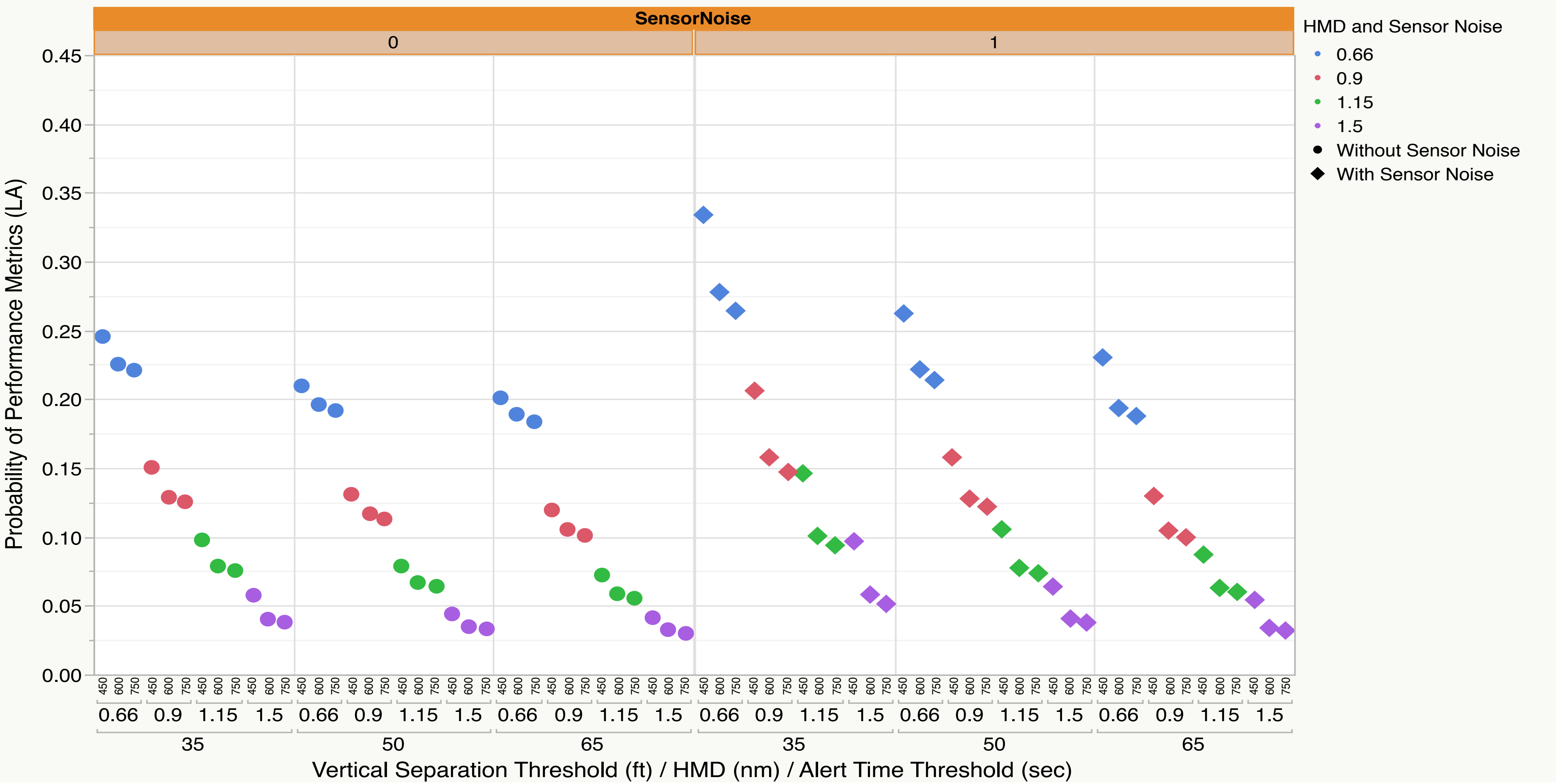
- Probability of Correct Required Alert (CRA)
- Probability of Missed Alert (MA)
- Probability of Late Alert (LA)
- Probability of Short Alert (SA)

# Probability of Missed Alert (MA)



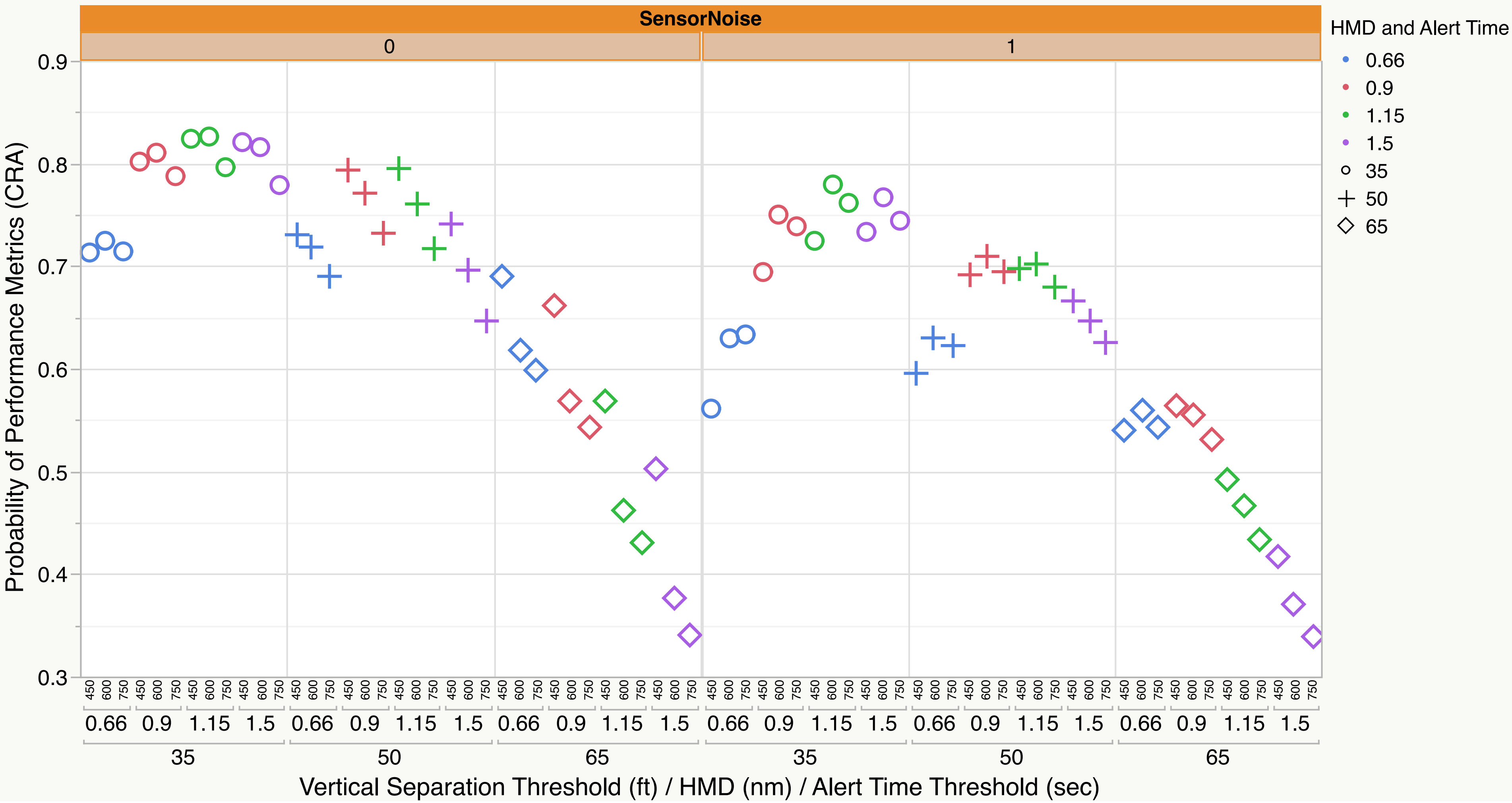

There is a significant effect of HMD and vertical threshold settings and sensor noise on the P(MA). On the other hand, there is no significant effect of alert time threshold on the P(MA).

# Probability of Late Alert (LA)



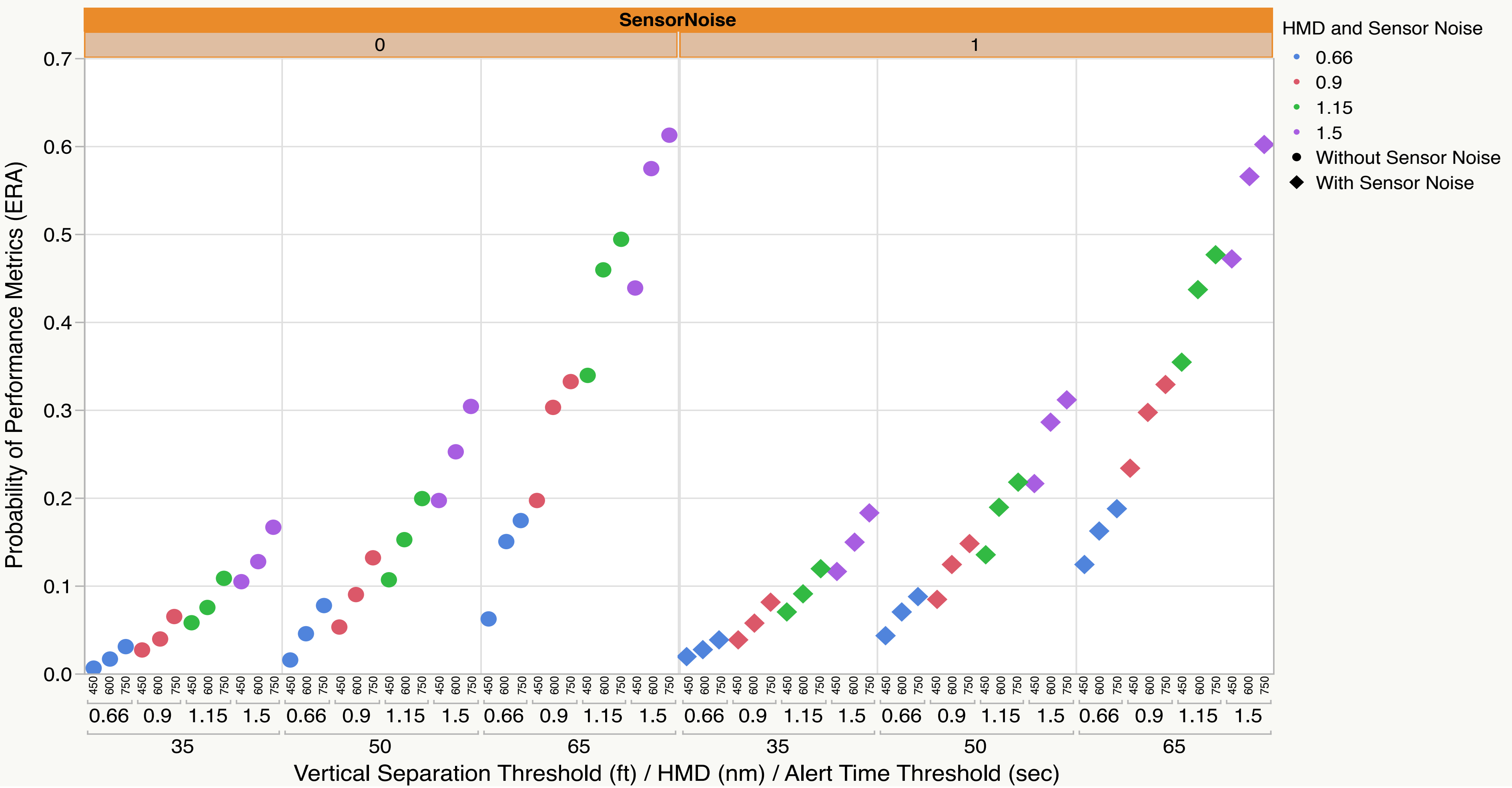

There is a significant effect of HMD/DMOD, vertical separation, and alert time thresholds on the P(LA). On the other hand, there is a less effect of sensor noise on the P(LA).

# Probability of Correct Required Alert (CRA)



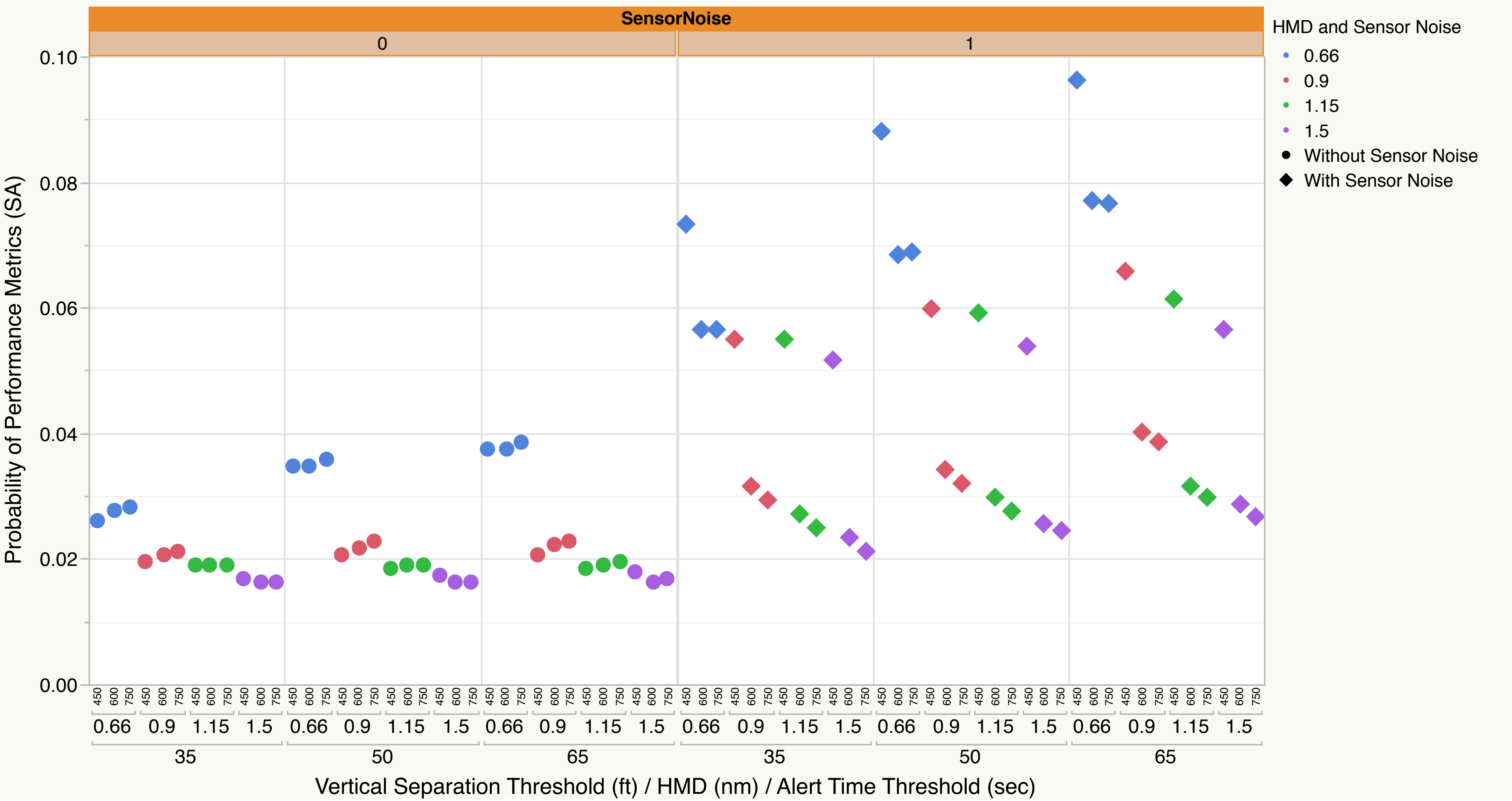

There is a significant effect of alert time threshold, HMD/DMOD, and sensor noise on the P(CRA).

# Probability of Early Required Alert (ERA)

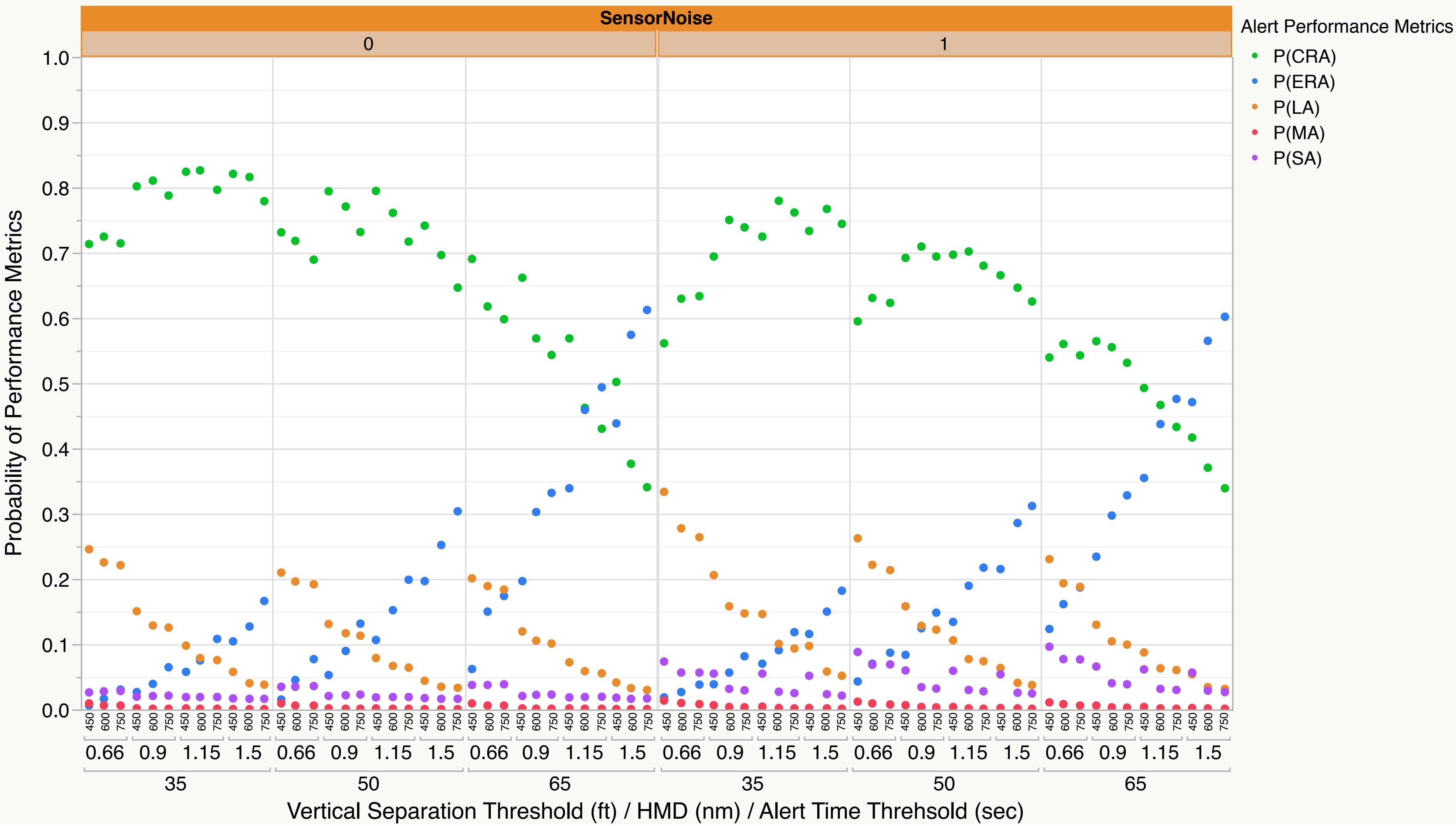



There is a significant effect of HMD/DMOD, alert time threshold, and vertical separation threshold on the P(ERA).

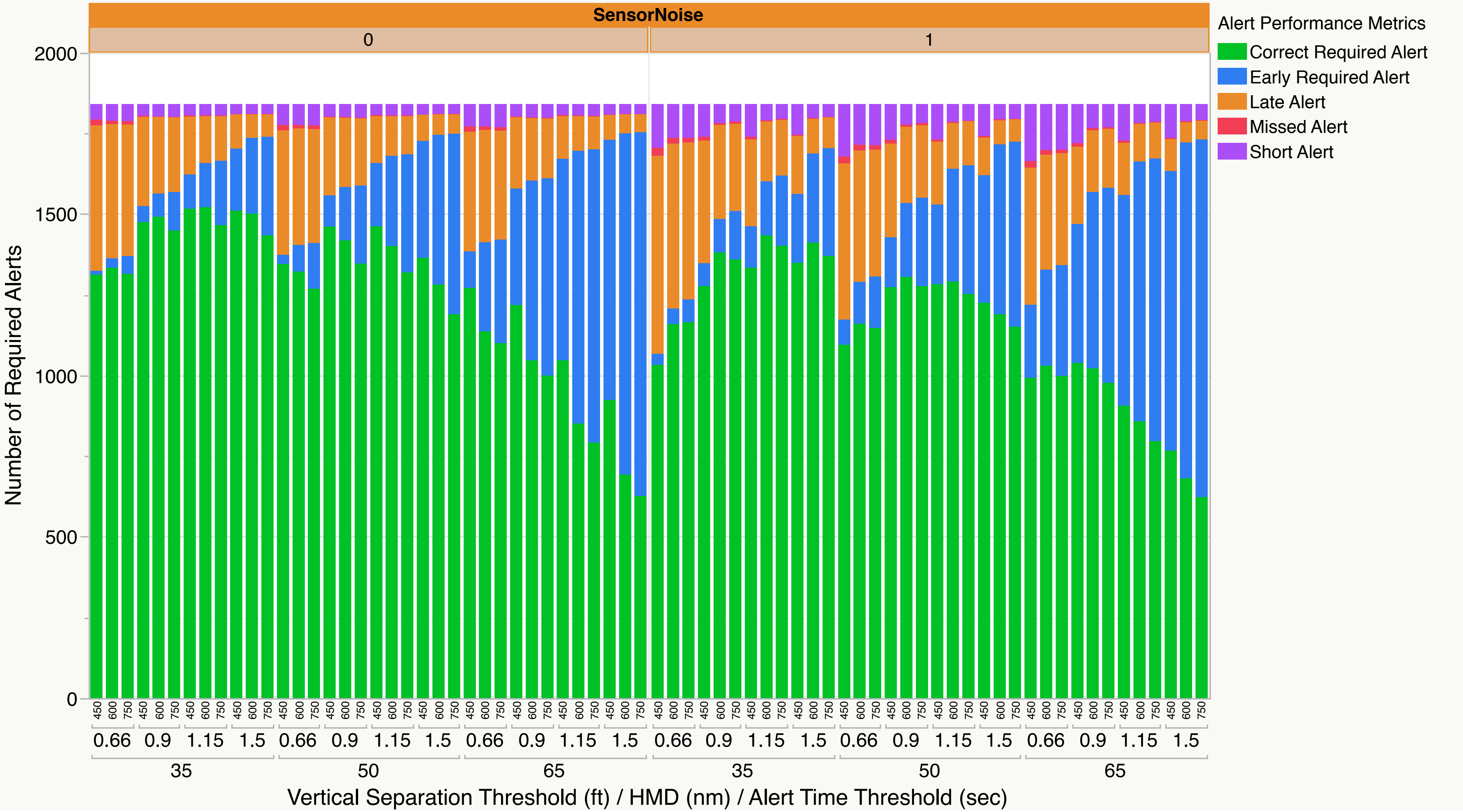
# Probability of Short Alert (SA)



# All Performance Metrics for DAA Required Warning Alerts



# Number of Required Warning Alerts

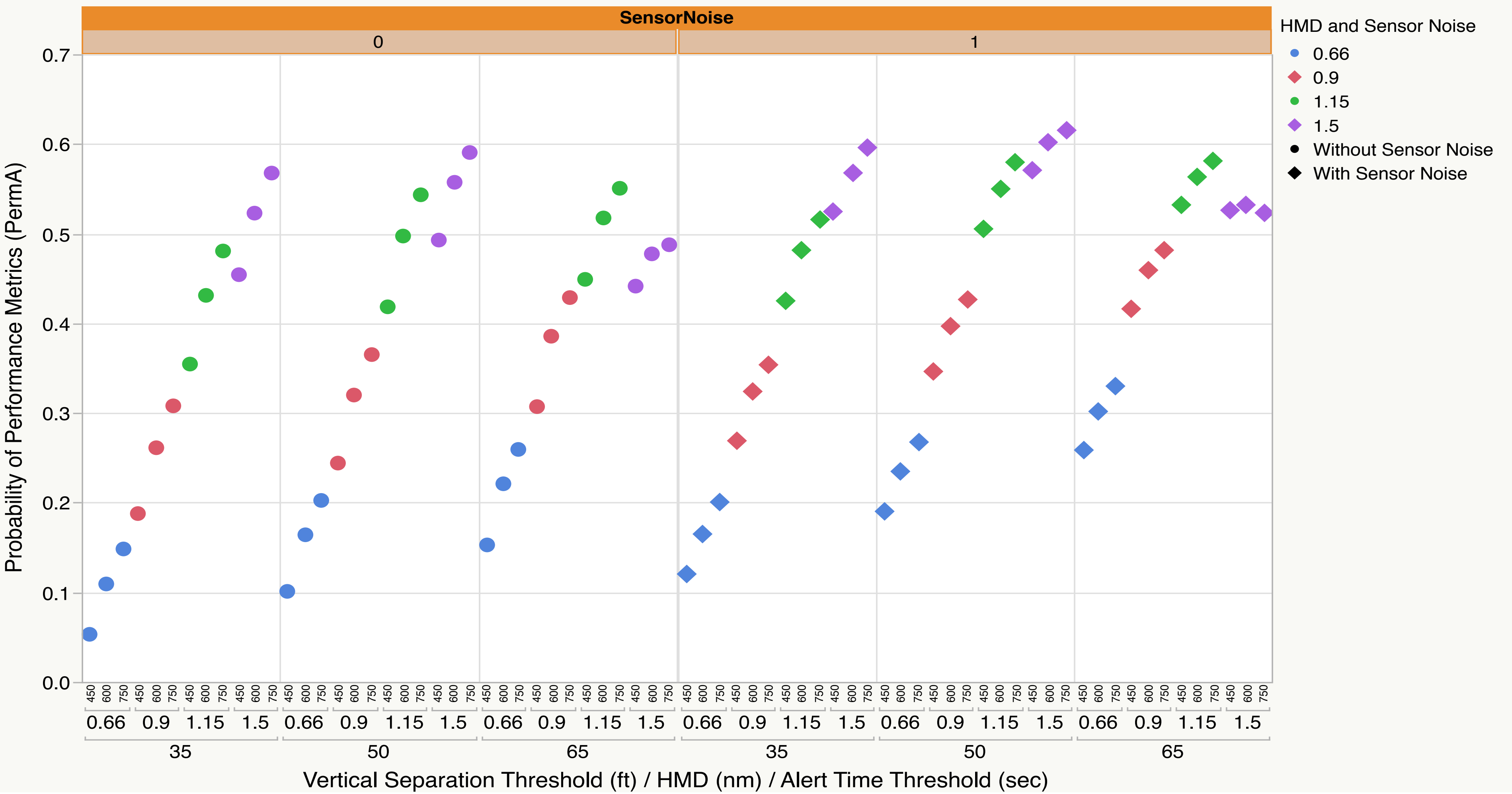


# Analysis for DAA Warning Alerts

## Performance Metrics Analyzing Tracks with MAZ Violation (Alerts Permissible)

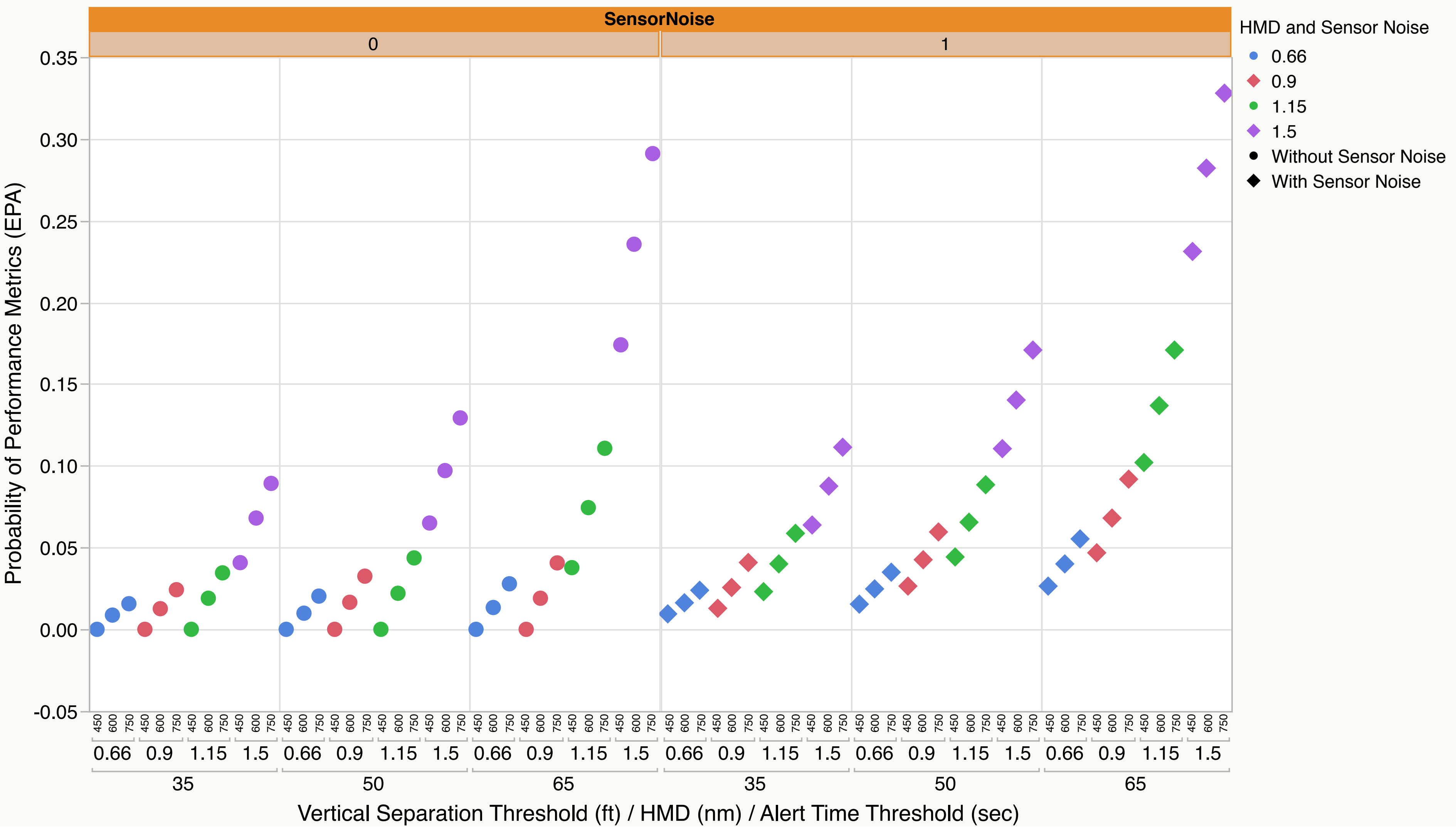
- Probability of Permissible Alert (PermA)
- Probability of Early Permissible Alert (EPA)
- Probability of Permissible Non-Alert (PNA)

# Probability of Permissible Alert




There is a significant effect of HMD/DMOD, alert time threshold, and vertical separation threshold on the P(PermA).

# Probability of Early Permissible Alert

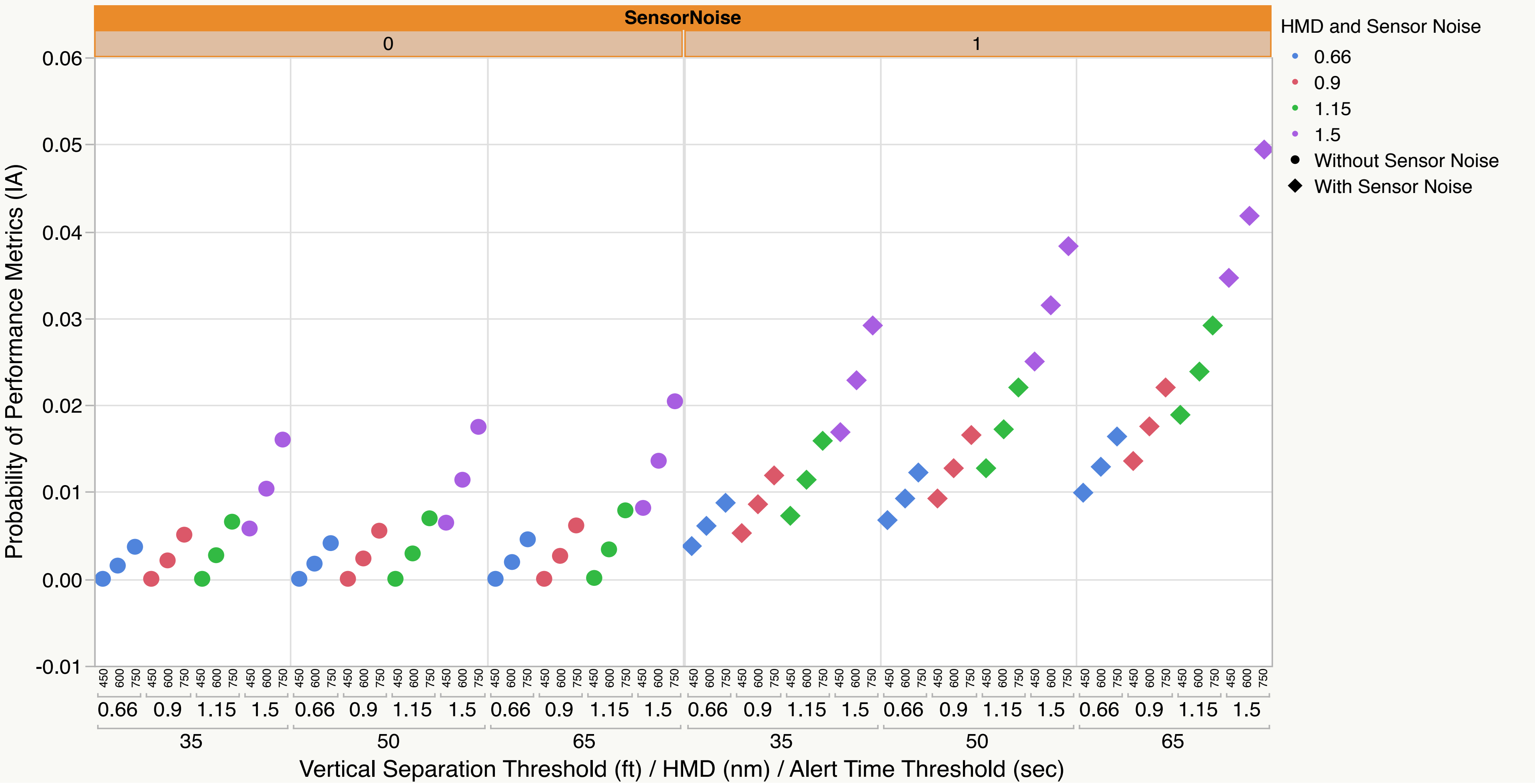


# Analysis for DAA Warning Alerts

Performance Metrics Analyzing Tracks remaining in Non-Hazard Zone (Alerts Undesirable)

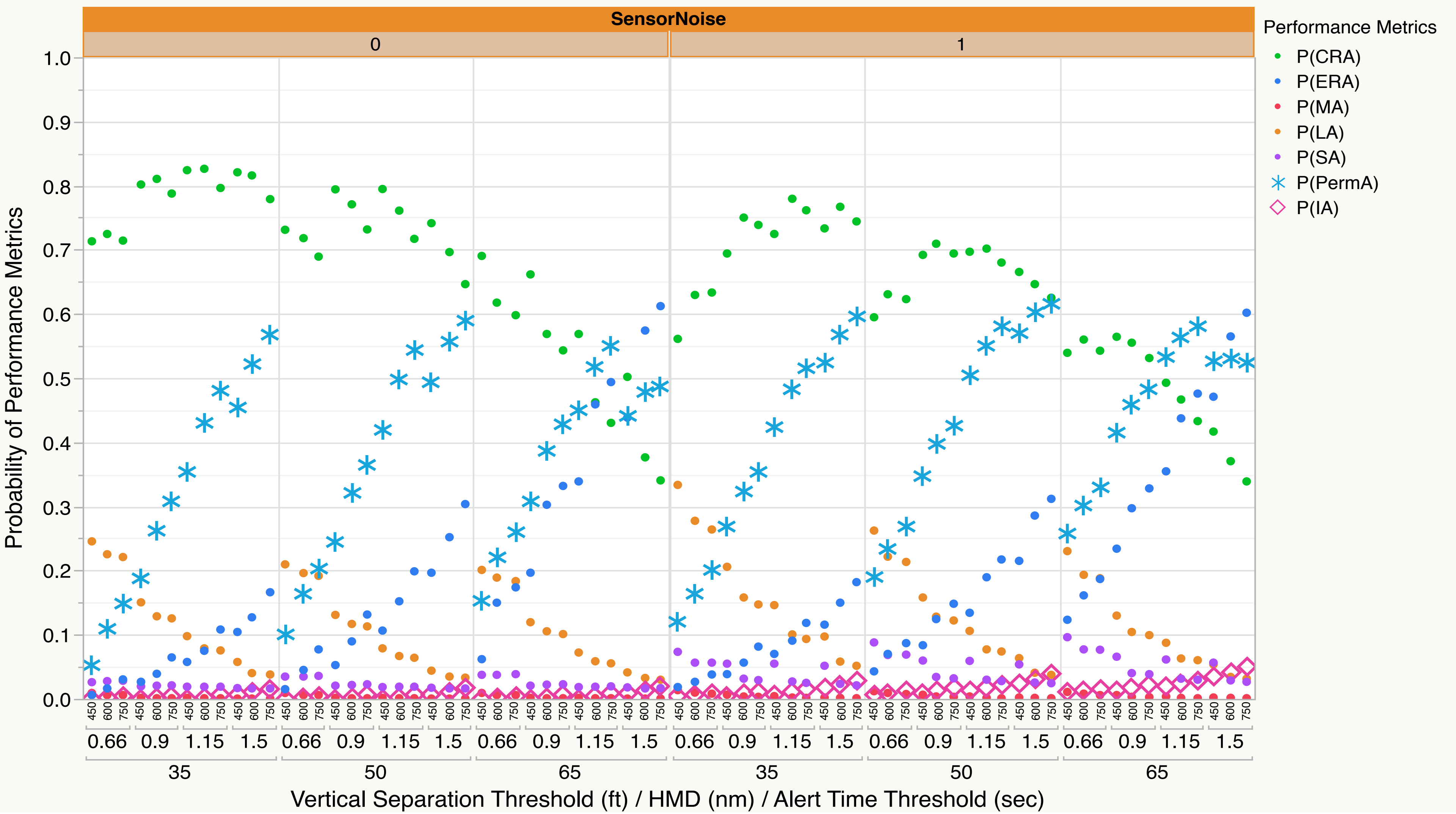
- Probability of Incorrect Alert (IA)
- Probability of Correct Non-Alert (CNA)

# Probability of Incorrect Warning Alert

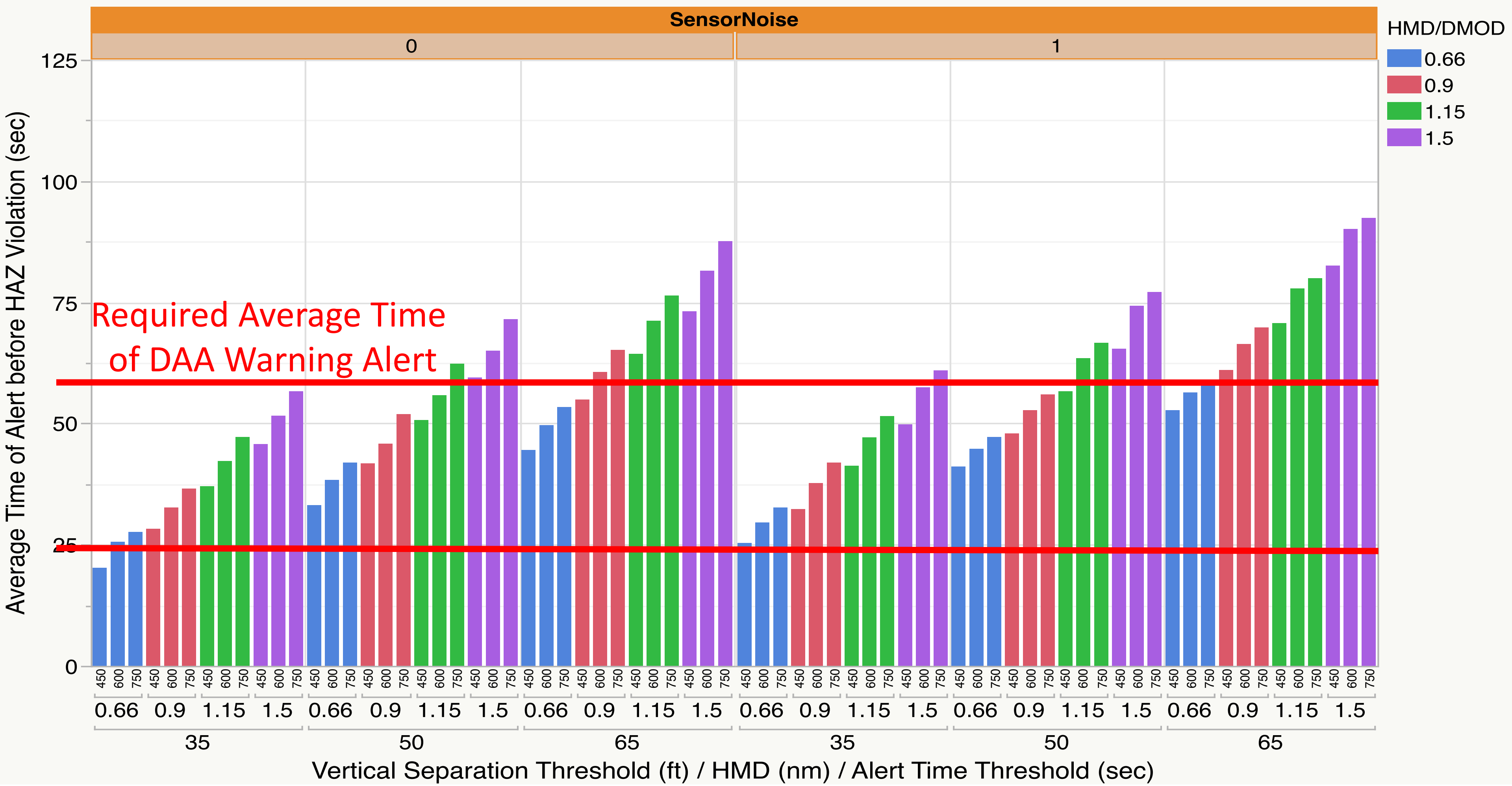



There is a significant effect of Sensor noise, HMD/DMOD, vertical separation, and alert time thresholds on the P(IA).

# All Performance Metrics for DAA Warning Alerts

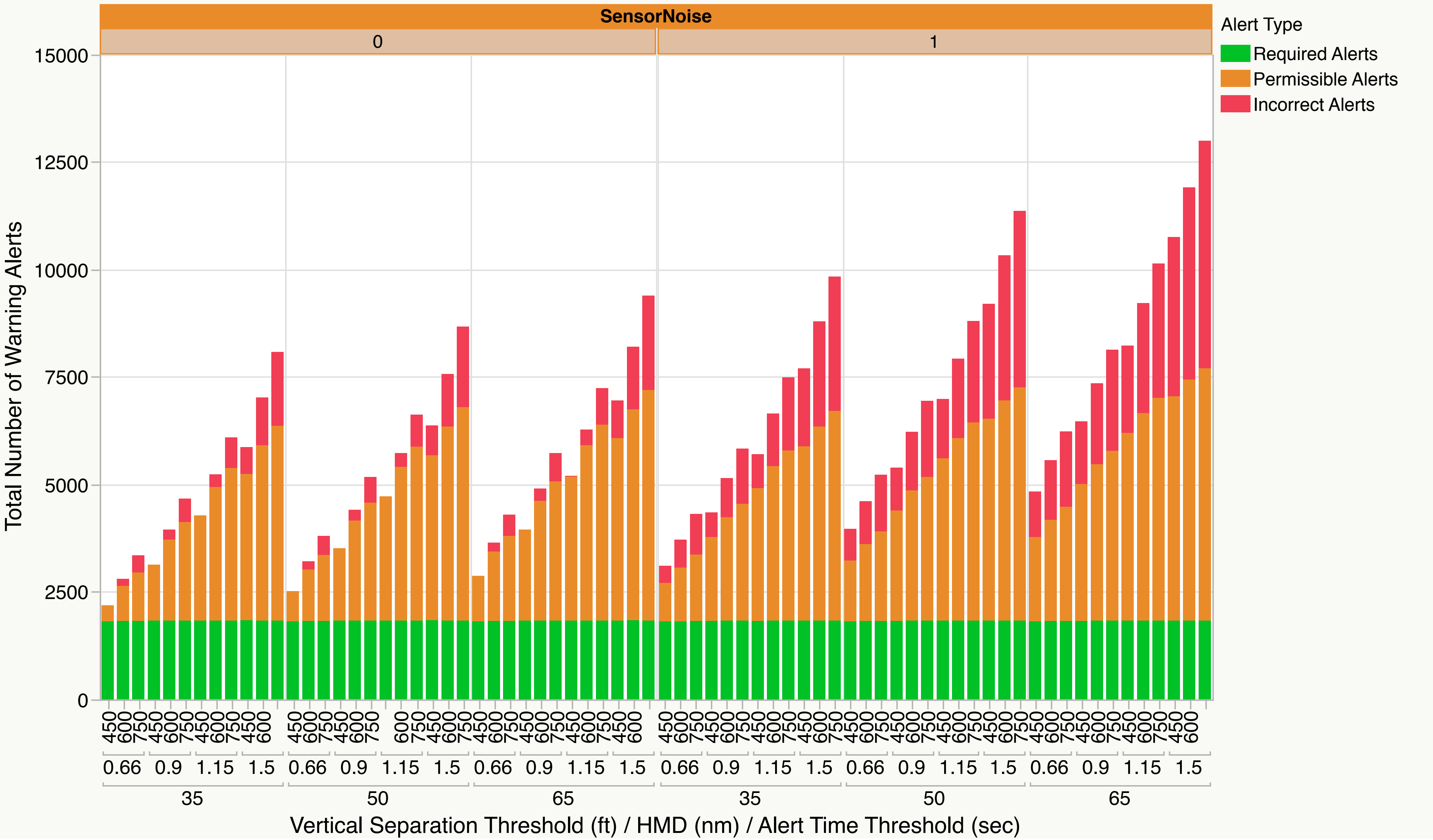


# Average Time of Warning Alert before HAZ Violation

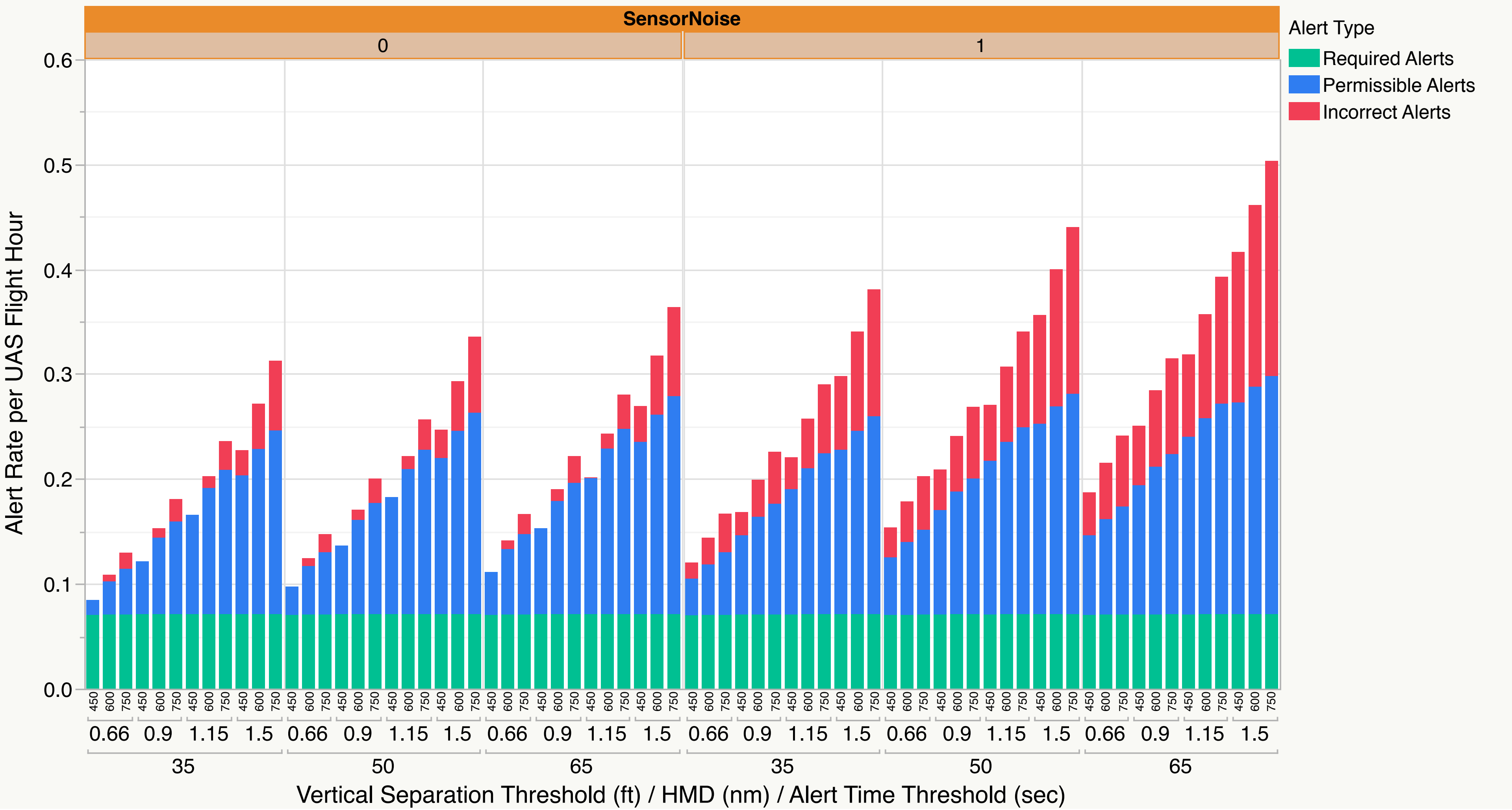



There is a significant effect of HMD/DMOD and Alert Time thresholds on the average time of alert. Vertical separation threshold has an effect on the average time of alert as well.

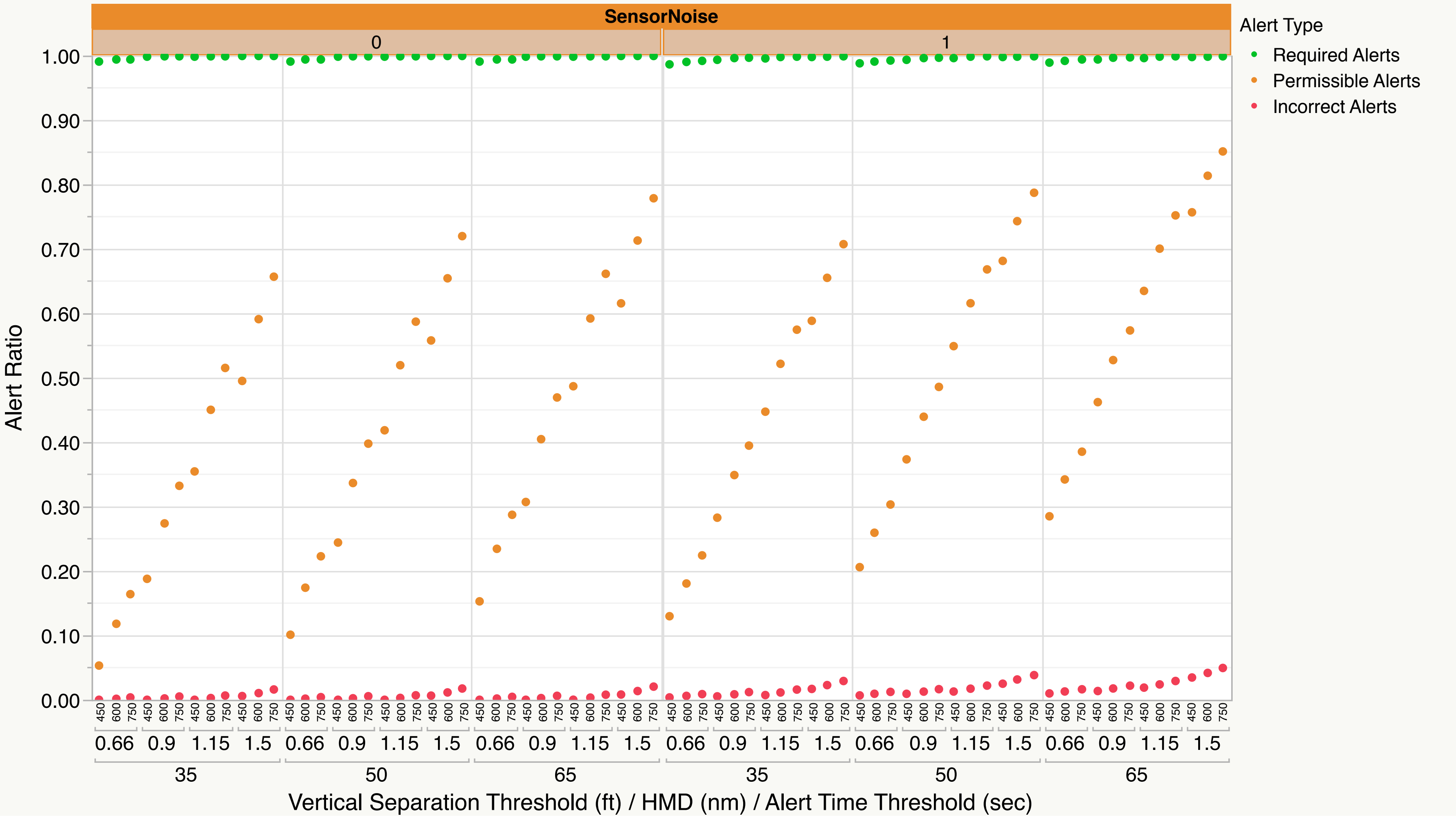
# Total Number of DAA Warning Alerts



# Warning Alert Rate per UAS Flight Hour



# Alert Ratio of DAA Warning Alerts



# Summary of Analysis (I)

- Overall, HMD/DMOD threshold has significant effect on the performance metrics.
- There is a noticeable effect of HMD/DMOD, vertical separation threshold, and sensor noise on the probability of Missed Alert, P(MA). On the other hand, DAA alert time threshold has less effect on the P(MA).
  - To reduce the P(MA), it would be better to have a larger HMD/DMOD threshold and a larger vertical separation threshold.
- There is a noticeable effect of HMD/DMOD, vertical separation, and alert time thresholds on the probability of Late Alert, P(LA). The HMD/DMOD threshold has the most significant effect on the P(LA). On the other hand, there is a less effect of sensor noise on the P(LA).
  - It would be also better to have a larger HMD/DMOD threshold, a longer alert time threshold, and a larger vertical separation threshold to reduce the P(LA).
- There is a noticeable effect of HMD/DMOD, vertical separation, and alert time thresholds on the probability of Early Required Alert, P(ERA). Alert Time threshold has more effect on the P(ERA) than on the P(LA). With a longer Alert Time threshold, it will increase the P(ERA) significantly while reducing the P(LA) a little bit.
- Alert time threshold and sensor noise have a noticeable negative effect on the probability of Correct Required Alert, P(CRA). On the other hand, Vertical separation threshold has less effect on the P(CRA).

# Summary of Analysis (II)

- The probability of Permissible Alert, P(PermA), is also significantly affected by the HMD/DMOD threshold, alert time threshold, and vertical separation threshold.
- There is a noticeable effect of sensor noise, HMD/DMOD and Alert Time threshold on the probability of Incorrect Alert, P(IA). HMD/DMOD threshold is much more sensitive factor to the P(IA) than the Alert Time threshold.
- There is noticeable effect of HMD/DMOD and Alert Time thresholds on the average time of alert. Vertical separation threshold has an effect on the average time of alert as well.
  - To meet the MOPS requirement on the minimum average time of alert for DAA Corrective Alerts (55 seconds), the HMD/DMOD threshold should be at least 0.9 nmi and alert time threshold would be better to set at least 50 seconds before HAZ when there is sensor noise.
  - Our results show that the requirement on the minimum average time of DAA Warning Alerts (25 seconds) can be satisfied even without any buffer on HMD/DMOD and with a shorter alert time threshold (35 seconds).
  - However, if HMD/DMOD threshold is larger than 1.15 and Alert Time threshold is larger than 50 seconds, it will increase the probability of Early Required Alert, P(ERA), significantly for DAA Warning alerts.

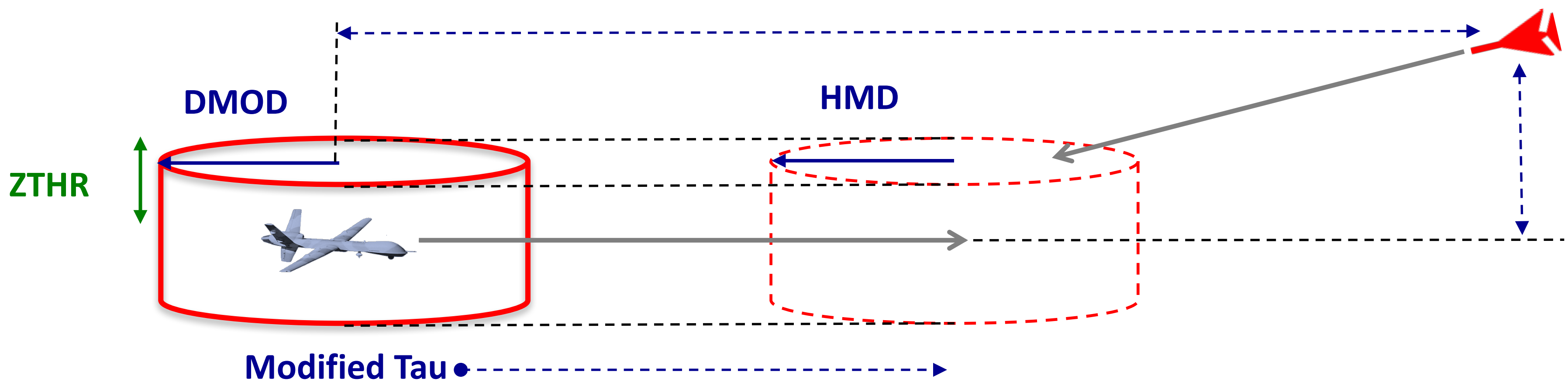
# Future Tradeoff Study

- Investigate the relationship between late/missed alerts and incorrect/early required alerts
  - Can we reduce the number of incorrect or early alerts without the immediate expense of higher late/missed alerts?
  - We might be able to reduce missed and late alerts with larger buffers, but it will increase the number of early or incorrect alerts.
  - Can we increase average alert time (AAT) without the expense of too many Early or Incorrect alerts?
- Further research on the effect of DAA Permissible alerts
  - Effect of the Permissible alerts on UAS pilot's performance
  - Permissible alerts might have more negative alerts than the early required alerts since the early required alerts are still correct alerts.
  - It might be desirable to reduce the number of all permissible alerts including early permissible alerts as well as the number of incorrect alerts.

# Backup Slides

# Definition of Loss of Well Clear

| Parameters | Values | Descriptions |
|---|---|---|
| Modified Tau | 35 sec | Ratio of range to range rate with DMOD |
| DMOD | 4,000 ft | Distance modification that represents a minimum desirable range between two aircraft |
| HMD | 4,000 ft | Horizontal distance at the predicted horizontal CPA |
| ZTHR | 450 ft | Current altitude separation |



# VFR Traffic (courtesy of 84th RADES)

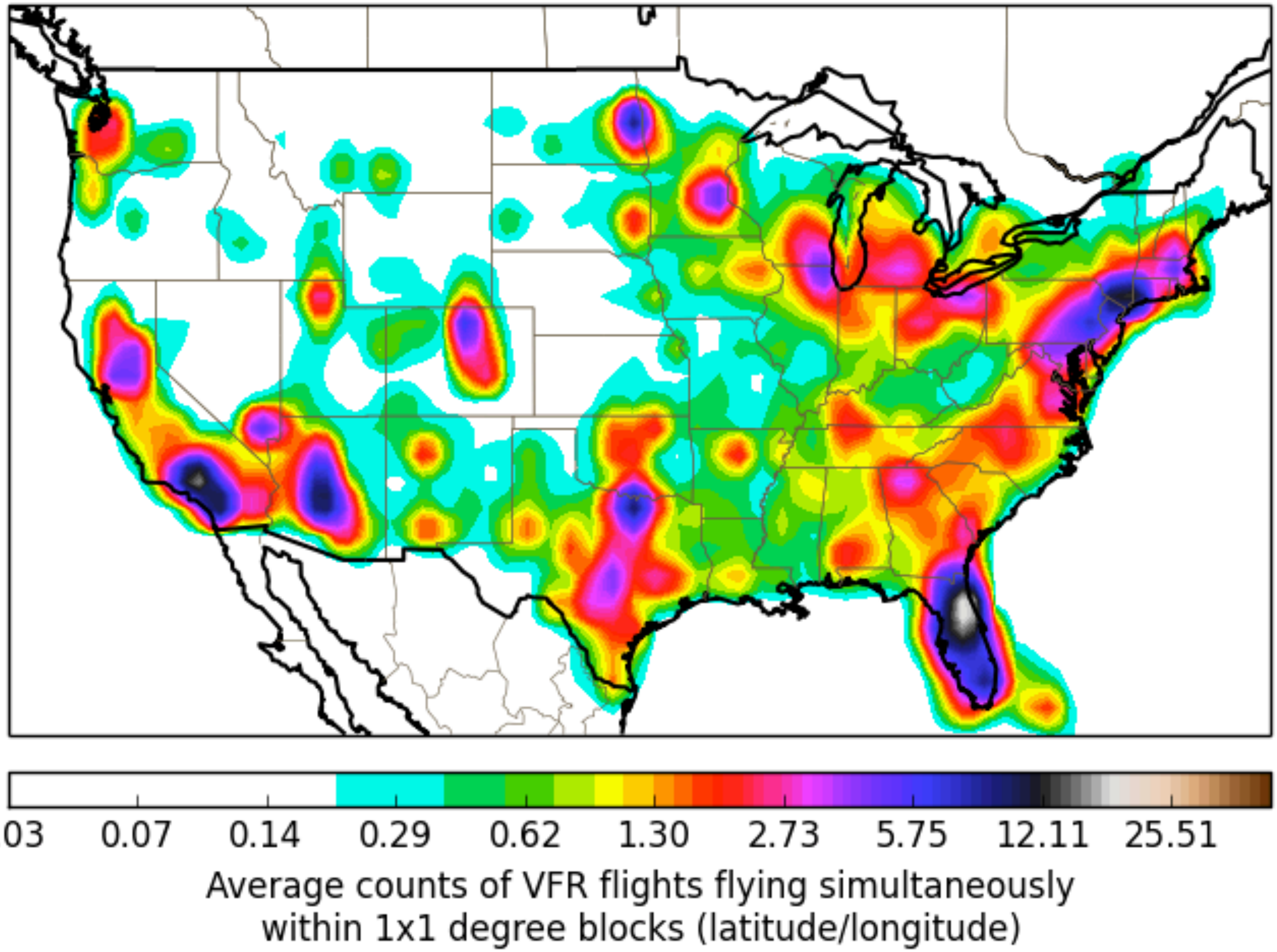
- The 84th Radar Evaluation Squadron (RADES) data were used.
  - There is no explicit information that could be used to determine whether radar hits come from IFR flights or VFR flights.
  - A single aircraft could be detected from multiple radar sites.

- Cooperative VFR tracks were processed using
  - A clustering method based on a modified minimum spanning tree algorithm,
  - Filters to categorize each track into IFR or VFR: altitude, speed, and Mode 3 code.

- Non-cooperative VFR tracks were processed
  - Using algorithm developed by Honeywell to process non-cooperative VFR tracks and estimates altitude measurements

- VFR tracks were smoothed using the IAI’s smoothing method

# Sample of Processed VFR Traffic: Geographic Flight Density




* Cooperative VFR Flight Profiles from April 4th, 2012